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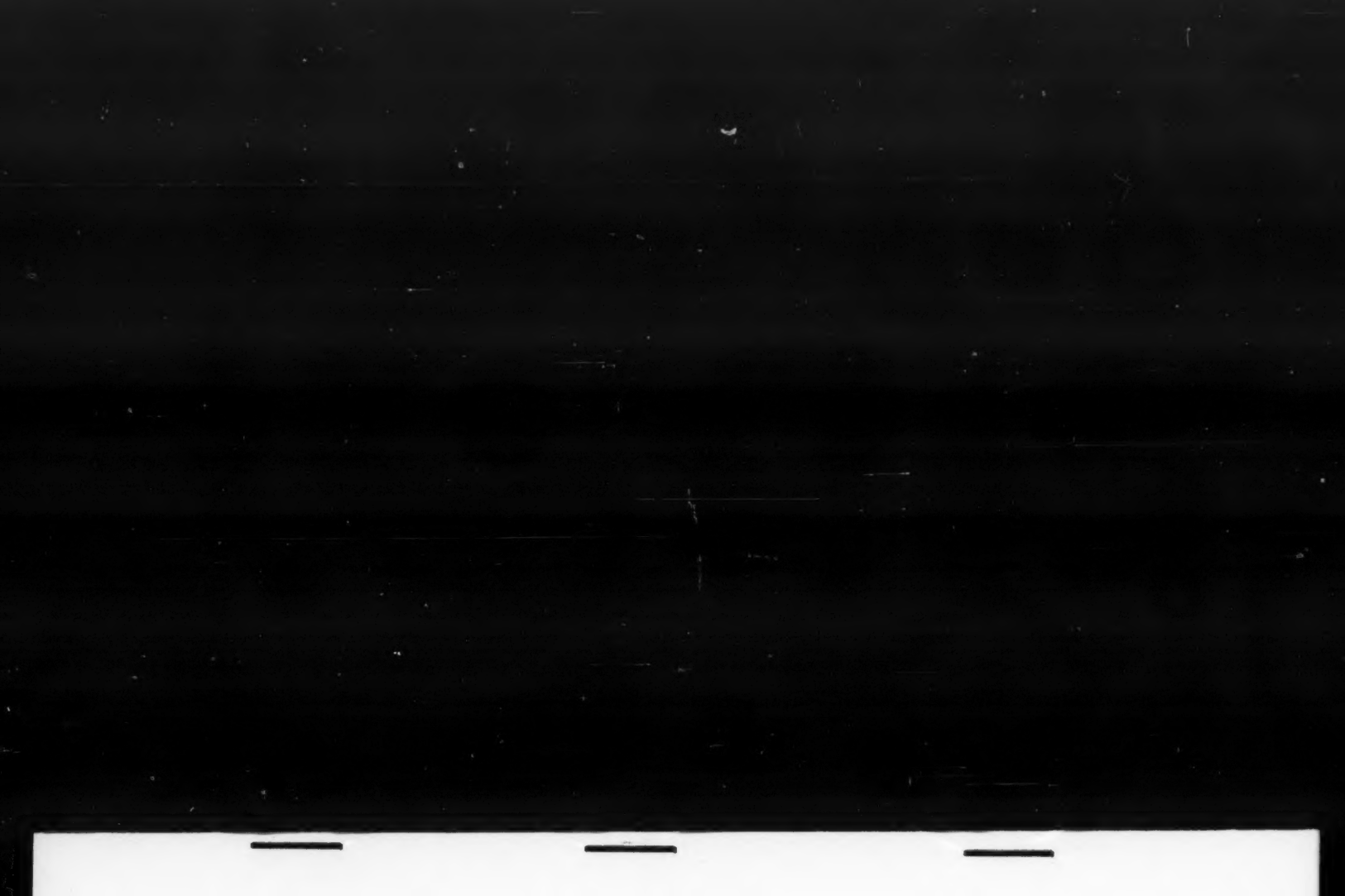

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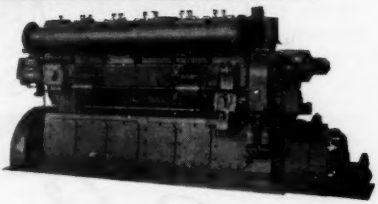

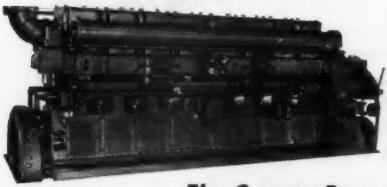

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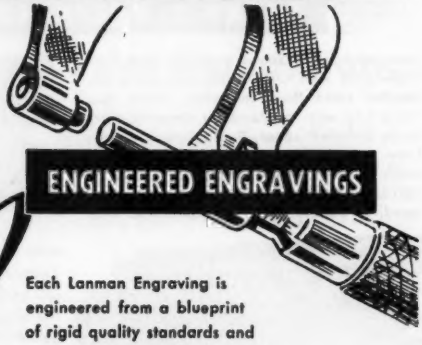

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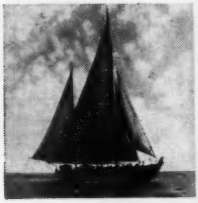

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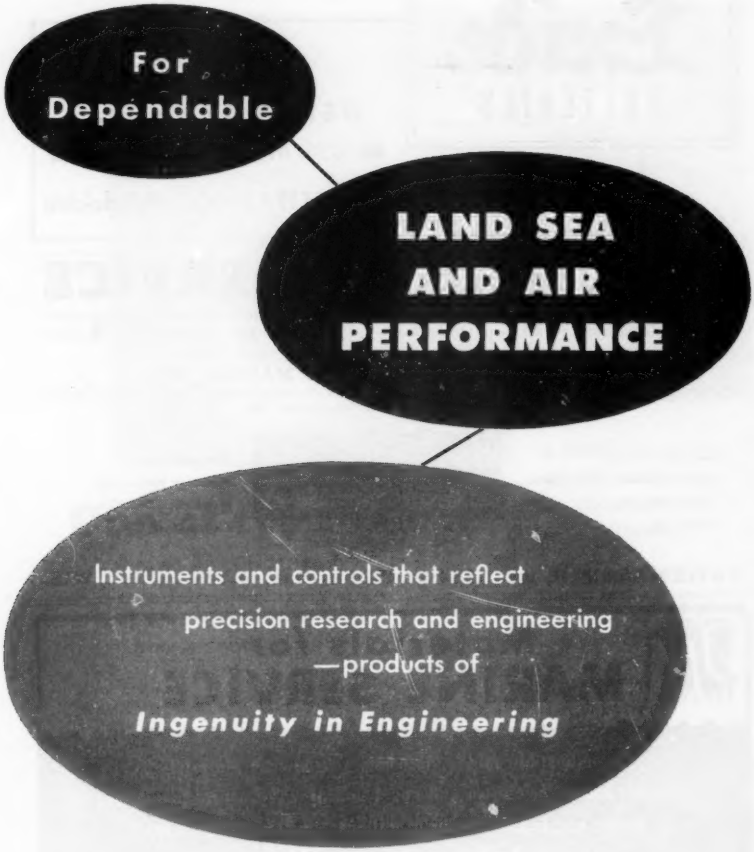

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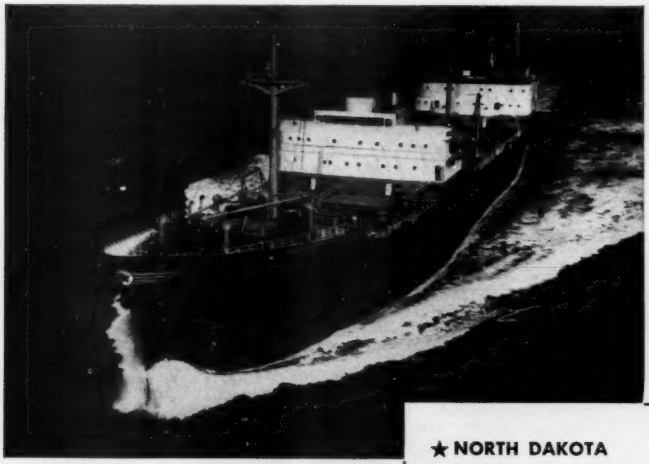

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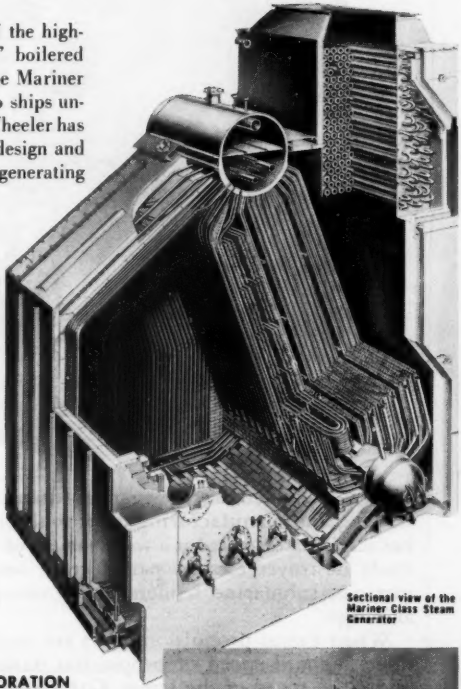

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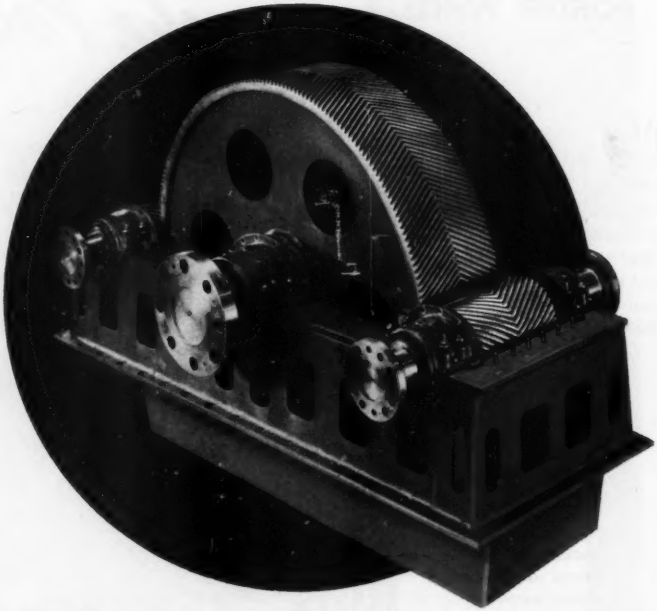

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Subject: INDEX OF ACP CHEMICALS FOR METAL PRESERVATION AND PAINT PROTECTION

METAL	OPERATION	ACP CHEMICAL
IRON AND STEEL	*Chromate Coating, in Preparation for Painting*	"CROMODINE"
	Cleaning	"ACP RIDOLINES AND RIDOSOLS"
	Cleaning for Painting	"DEOXIDINE" "DURIDINE"
	Coating with Copper	"CUPRODINE"
	Drawing and Extrusion	"GRANODRAW"
	Paint Bonding	"CROMODINE" "DURIDINE" "GRANODINE" "PERMADINE" "THERMOIL-GRANODINE"
	Paint Stripping	"CAUSTIC SODA AND SOLVENT NO. 3"
	Phosphate Coating, in Preparation for Painting	"DURIDINE" "GRANODINE" "PERMADINE" "THERMOIL-GRANODINE"
	Phosphate Coating, to Protect Friction Surfaces	"THERMOIL-GRANODINE"
	Pickling with Inhibited Acids	"RODINE"
	Rust Prevention for Unpainted Iron	"PEROLINE"
	Rust Proofing	"PERMADINE" "THERMOIL-GRANODINE"
	Rust Removal—Brush, Dip, or Spray	"DEOXIDINE"
	Soldering Flux	"FLOSOL"
GALVANIZED IRON, ZINC, AND CADMIUM	*Cleaning*	"DURIDINE" "ACP RIDOLINES AND RIDOSOLS"
	Corrosion Proofing	"ZINODINE"
	Paint Bonding	"ZINODINE"
	Phosphate Coating, in Preparation for Painting	"LITHOFORM"
	Soldering Flux	"FLOSOL"
ALUMINUM	*Cleaning*	"DEOXIDINE" "DURIDINE" "ACP RIDOLINES AND RIDOSOLS"
	Preparation for Painting	"ALODINE" "DURIDINE" "DEOXIDINE"
	Protection from Corrosion	"ALODINE"

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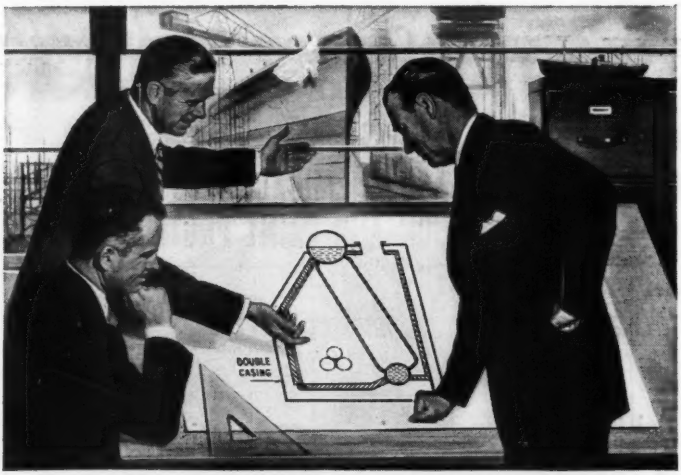
CHEMICALS ACP PROCESSES



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NOTICE

THE ANNUAL BANQUET

of

THE AMERICAN SOCIETY OF NAVAL ENGINEERS

for

1954

will be held in

Washington, D. C.

on 30 April 1954

at the

STATLER HOTEL

REAR ADMIRAL E. W. SYLVESTER, U.S.N., *President of the Society, will Preside.*

MR. WILLIAM E. BLEWETT, JR., *President of the Newport News Shipbuilding and Dry Dock Company, will officiate as Toastmaster.*

VICE ADMIRAL E. L. COCHRANE, U.S.N., Retired, *Dean of Engineering, Massachusetts Institute of Technology, will be the Speaker.*

1953-1954 COUNCILS—JOINT MEETINGS

Front Row: Captain Bittinger, 1952-53 Council Member; Mr. Carleton, 1953-54 Council Member; Rear Admiral Sylvester, President; Rear Admiral McShane 1952-53 Council Member; Commander Thompson, 1952-53 Council Member; Mr. Fessenden, Administrative Assistant. *Back Row:* Mr. Kennedy, 1952-53 Council Member; Commander Naab, 1954-55 Council Member; Captain Madden, Assistant Secretary-Treasurer; Captain Webster, 1954-55 Council Member; Mr. Hanlon, 1954-55 Council Member; Captain Honsinger, 1954-55 Council Member; Commander Campbell, 1954-55 Council Member; Captain Snyder, 1953-54 Council Member; Captain Chambers, 1953-54 Council Member; Captain Hamilton, Secretary-Treasurer; Captain Harrison, 1953-54 Council Member; Captain White, Chairman Ballot Counting Committee. *Absent:* Rear Admiral Wallin, 1953- elected president; Captain Grimes, 1952-53 Council Member.

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JOURNAL

OF

THE AMERICAN SOCIETY OF NAVAL ENGINEERS, INC.

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Statements contained in articles herein are the private opinions and assertions of the writers and should therefore not be construed as reflecting the views of The American Society of Naval Engineers, Inc., nor of any other organization with which such writers are affiliated.

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COUNCIL OF THE SOCIETY

(Under whose supervision this number is published).

Rear Admiral Evander Wallace Sylvester, U. S. N., President

Commander C. H. Campbell, U. S. N. R.
Captain I. V. Honsinger, U. S. N.
Mr. H. E. Carleton
Commander J. W. Naab, U.S.C.G.
Captain G. M. Chambers, U. S. N.
Captain P. W. Snyder, U.S.N.
Mr. J. F. Hanlon
Captain Hugh Webster, U. S. N.
Captain R. E. W. Harrison, U.S.N.R.

Captain J. E. Hamilton, U.S.N., (Ret.), Secretary-Treasurer

SECRETARY'S NOTES

THE 1954 ELECTION

At a Council Meeting on 29 December 1953, the following results of the 1954 election were confirmed.

Elected as President for 1954:

Rear Admiral Evander Wallace Sylvester, U.S.N.

Re-elected as Secretary-Treasurer for 1954:

Captain J. E. Hamilton, U.S.N., Ret.

Counting Committee. *Absent:* Rear Admiral Wallin, 1953- elected president; Captain Grimes, 1952-53 Council Member.

Elected as members of the Council for 1954-5:

Regular Navy Officers:

Captain L. V. Honsinger, U.S.N.
Captain Hugh Webster, U.S.N.

Coast Guard Officer:

Commander J. W. Naab, U.S.C.G.

Naval Reserve Officer:

Commander C. H. Campbell, U.S.N.R.

Civilian Member:

Mr. John F. Hanlon

THE COUNCIL

Membership

In addition to the five new members who have just been elected to serve for two years, the following members will serve during 1954.

Mr. H. E. Carleton
Captain G. M. Chambers, U.S.N.
Captain R. E. W. Harrison, U.S.N.R.
Captain P. W. Snyder, U.S.N.

Meeting

At a joint (1953-1954) Council Meeting on 29 December 1953, the following business was conducted:

The election results were received and confirmed.

The continuation of Captain R. B. Madden, U.S.N., as Assistant Secretary-Treasurer, and of Mr. Arthur G. Fessenden as Administrative Assistant (former Title "Clerk") was approved.

A committee under the chairmanship of Commander Campbell, with Mr. Hanlon and Commander Naab as additional members was appointed to consider the matter of changing the by-laws to provide for student memberships at a reduced cost.

ANNUAL BANQUET

The Annual Banquet of the Society will be held at the Statler Hotel in Washington, D. C., on Friday, 30 April 1954. General arrangements will be similar to past years. Details and reservation forms will be in the hands of members in early March.

We are very happy to announce the selection and acceptance as Principal Speaker at the banquet:

Vice Admiral E. L. Cochrane, U.S.N., Retired
Dean of Engineering, Massachusetts Institute of Technology

and as Toastmaster:

Mr. William E. Blewett, Jr.
President of the Newport News Shipbuilding and Dry Dock Co.

UNIVERSITY OF MICHIGAN HONORS MARINE ALUMNI

Fourteen members of the University of Michigan's College of Engineering, Department of Naval Architecture and Marine Engineering, were among the 240 alumni honored for distinguished contributions to their professions during the university's recent Centennial of Engineering. Among those cited were the following members of the Society:

Nicholas J. Brazell
Mark L. Iveland, Jr.
William C. Reynolds
Leigh R. Sanford

THE BUREAU OF SHIPS AND ITS E.D. OFFICERS

This article which is published in this issue of the JOURNAL was initially suggested by Admiral S. M. Robinson, U.S.N., Retired. Admiral Robinson needs no introduction to members of the Society. He was its Secretary-Treasurer in 1921-3 and its President in 1931 and 1939.

Preliminary to the Madden paper, but not connected with it in any way, we published "The Origin of Engineering Duty Only" by Captain Bassler in the November 1953 issue. Captain Bassler's paper was based on a thorough and painstaking review of *official published sources*. Quite naturally these sources do not divulge very much in the way of detail and cannot reveal many intimate underlying and subsidiary (even causal) events.

Beginning with a staff article in November 1951 "Designated Engineering Duty Only" we have presented, as completely as we could, all phases of the subject. The article by Captain Bassler was voluntarily submitted and was accepted because it contributed to the effort to make the EDO presentation complete. It is necessary to interpret the title of Captain Bassler's paper in a literal way. He does not describe the mechanics of obtaining the legislation which made "E.D.O." an official term descriptive of the class of naval officers who were technically educated and experienced to handle the Navy's increasingly complex problems of research and development, design, procurement, installation and maintenance of *machinery*.

Captain Bassler, in his meticulous review, seems to us to have laid the philosophical basis on which *something* had to be established. He does not explain why or how that "something" turned out to be the setting up of a group of regular line officers who, by selection from a group of volunteers, were designated for "Engineering Duty Only." This *official* designation deprived these officers of the right to command ships and even to be ordered to sea duty after reaching the rank of Commander. They could volunteer for sea duty in a limited number of staff billets. On the other hand the EDO's career was protected so that he could devote his efforts to his first love—engineering matters.

Bassler makes it clear that, as the old Engineer Corps died out, a serious need was created for something to take its place. The solution was not easy to reach because of wide differences of opinion between and among civilian and officer officials of the Navy Department. It was fortuitous that then Commander Robinson devised the E.D.O. concept and that the Secretary of the Navy Josephus Daniels became aware of it and was able to have it enacted into legislation because of his position of leadership in his political party.

It seems apparent that the E.D.O. concept proved its correctness during the period from 1916 to 1940. It was questioned when the Construction Corps and the E.D.O.'s were joined into one group but the line specialist concept prevailed over the "staff" concept. This has now had a fourteen-year trial and has so far proven sound. Whether or not the matter is closed for all time is doubtful. At the present time it is our editorial opinion that an adverse cataclysm in naval engineering affairs or a political *coups d'etat* must occur before serious consideration will be given to replacing the E.D.O. concept with something else.

BUSHIPS FOLLOW-UP

The second article in this issue is a perfect companion-piece to the first. In the *Timmerman,* which is described as a modern *Clermont,* is packaged much of the technical hope of the Bureau of Ships and of its ED's. This ship may someday be recognized as a more important product of the Bureau than is its phenomenal World War II shipbuilding program. It may startle some to learn that the *Timmerman* was conceived, contracted for and started during the early days of World War II under the first Chief of the Bureau of Ships.

CHIEFS OF THE BUREAU OF SHIPS

This picture, taken 8 July 1953, shows all of the past Chiefs of the Bureau. The present Chief, Rear Admiral W. D. Leggett, Jr., USN, was Deputy Chief at the time and is not included in the picture. Left to right: Admiral S. M. Robinson, Rear Admiral A. H. Van Keuren, Vice Admiral E. L. Cochrane, Vice Admiral E. W. Mills, Rear Admiral D. H. Clark, and Rear Admiral H. N. Wallin.

THE BUREAU OF SHIPS AND ITS E. D. OFFICERS

CAPTAIN ROBERT B. MADDEN, USN

THE AUTHOR

graduated from the U. S. Naval Academy in 1933, completed a postgraduate course in Naval Construction at Massachusetts Institute of Technology in 1938, and completed the Advanced Management Program at Harvard Graduate School of Business Administration in 1947. He was commissioned in the Construction Corps in 1936 and became an Engineering Duty (ED) officer in 1940. Presently serving in the Bureau of Ships, he is the Assistant Secretary-Treasurer of the Society.

Public Law 644, enacted by the 76th Congress on 20 June 1940, abolished the Bureau of Engineering and the Bureau of Construction and Repair, and consolidated their functions under a new Bureau of Ships. Five days later the same Congress, by Public Law 657, did away with the Construction Corps and amalgamated its members with those officers of the Line who were designated "Engineering Duty Only" (EDO). This is the story of the Bureau of Ships and its personnel consolidation.

HISTORICAL BACKGROUND OF THE BUREAUS

In 1937 Rear Admiral Robert wrote a thorough and interesting report on the history of the Construction Corps and of the Bureau of Construction and Repair.[1] Likewise a staff article in the Journal of the American Society of Naval Engineers in 1951 presented a complete history of the Bureau of Engineering and of the EDO group[2]. In order to provide the setting for the events immediately leading up to the formation of the Bureau of Ships in 1940, certain of the material in those two treatises will be repeated herein, together with a review of previous amalgamation efforts.

Prior to 1842 there were no Bureaus in the Navy Department. For 27 years before that date the Navy Department was operated by the Secretary assisted by a Board of Navy Commissioners composed of three naval officers. This system assigned no individual responsibilities to these officers, but rather assigned them "collective accountability and collective management"[3]. This very feature proved to be the downfall of the system, with the result that on 31 August 1842, Congress established the Bureau system. One of the new Bureaus was the Bureau of Construction, Equipment and Repair. It is in-

H. N. Wallin.

teresting to note that this Bureau was allowed one draftsman and four clerks!

The Bureau of Construction, Equipment and Repair was responsible for the design, construction, outfitting and repair of ships, including the steam engineering phases thereof. This centralization of shipbuilding responsibilities was perfectly logical inasmuch as steam engineering was barely in its infancy. Although two sidewheel steamers, *Mississippi* and *Missouri* were built in 1841 and the first screw-propeller ship, *Princeton*, was built in 1843, up until 1860 steam power was used for auxiliary purposes, sails still being considered as the primary source of propulsion. But about the time the Civil War broke out, steam power came into its own and sails were relegated to the auxiliary means of propulsion.

This rise in importance of steam engineering, coupled with other developments in the Navy, caused Congress on 5 July 1862 to establish eight Bureaus to take the place of the five then in existence. The duties of the former Bureau of Construction, Equipment and repair were distributed among three new Bureaus, viz: Steam Engineering, Construction and Repair, and Equipment and Recruiting.

For the next twenty years no changes were made in the Bureau system, and from records available to the author no strong representations were made for any changes. This can probably be attributed to a widespread indifference to the Navy on the part of the people and Congress. Then in 1883, in his annual report, Secretary William E. Chandler recommended the formation of a single Bureau of Naval Construction, to result from combining the Bureau of Construction and Repair and the Bureau of Steam Engineering[4]. In 1885 Secretary William C. Whitney recommended that all material responsibilities, including ordnance, be placed in one Bureau to be called the Bureau of Material and Construction. In 1886 Admiral Porter likewise recommended combining the two ship materiel Bureaus into a Bureau of Construction, Steam Engineering and Repair. Nothing came of any of these three recommendations.

In 1889 Secretary Benjamin F. Tracy removed the handling of enlisted personnel from the Bureau of Equipment and Recruiting, assigning to that Bureau in its place the cognizance of all electrical equipment aboard ship. Shortly thereafter the name of that Bureau was changed to the Bureau of Equipment. Secretary Tracy also created the Board of Construction, composed of the Chiefs of the Bureaus of Steam Engineering, Construction and Repair, Equipment, Ordnance, and Yards and Docks. This Board was in existence for 20 years.

In 1899 Secretary John D. Long recommended the consolidation of the Bureaus of Construction and Repair, Steam Engineering, and Equipment.[5] Again approval was not forthcoming. But by 1909 the inter-Bureau discords and disputes came to a head. Early in that year, when the billet of the Chief of the Bureau of Steam Engineering became vacant, Secretary Truman H. Newberry appointed the Chief of the Bureau of Construction and Repair (Chief Constructor Washington L. Capps) to additional duty as Chief of the Bureau of Steam Engineering, thus in effect consolidating the two Bureaus. This action was determined to be illegal, and so the consolidation lasted only a few months.

At the same time (January 1909) Secretary Newberry recommended to President Roosevelt a complete reorganization of the Navy Department. According to the Newberry Plan there would be three large "divisions," one of which would be under the Board of Construction and would consist of the Bureaus of Steam Engineering, Ordnance, and Construction and Repair. President Roosevelt appointed the

Moody Board to study the Newberry plan, and from a material standpoint the Board agreed with Secretary Newberry. But no action was taken because President Taft came into office in March 1909 and George von L. Meyer was appointed Secretary of the Navy.

Secretary Meyer, based on the recommendations of the Sperry Board and the Swift Board[8] attempted to provide for greater coordination between the Bureaus by developing an aide system, including an aide for material. He also transferred all machinery, except electrical, to the Bureau of Steam Engineering, and later practically abolished the Bureau of Equipment by transferring its duties to other Bureaus, including electric generators, signal apparatus and wireless-telegraphy outfits to the Bureau of Steam Engineering. Finally, the Naval Appropriations Act of 30 June 1914, expressly abolished the Bureau of Equipment.

Upon the assumption of its responsibilities for electrical equipment, it was realized that the name of the Bureau of Steam Engineering was not descriptive of its over-all task. But it was six years before action was taken; on 4 June 1920 it became the Bureau of Engineering.

Following World War I, there arose considerable agitation for departmental reorganization, with the result that a Navy Department Reorganization Board, with Rear Admiral Edwin A. Anderson as senior member, was set up on 20 June 1921. One of the areas this Board was directed to look into was "the assembling under one office or Bureau in the Department of matters pertaining to one subject".[55] The Bureau of Construction and Repair member, Captain (later Rear Admiral) W. G. DuBose, and the Bureau of Engineering member, Captain (later Admiral) A. J. Hepburn, agreed that certain steps tending toward the amalgamation of the two Bureaus should be taken. However, the Chief of Naval Operations, Admiral R. E. Coontz, was not in agreement and Secretary Denby orally directed the Board to steer their actions into other channels.

At about this time interest in the Navy faded, and although there were attempts in the 20's to consolidate personnel it wasn't until 1933 that the subject of organizational changes was again raised. Chairman Carl Vinson of the House Naval Affairs Committee presented a reorganization proposal, similar to the one he was to propose six years later in 1939. Then on 8 May 1933 Secretary Claude A. Swanson convened a Board to "consider and recommend upon the reorganization of the Navy Department and the amalgamation of certain or all Staff Corps and the Marine Corps with the Line of the Navy." In its report[6] dated 6 November 1933 this Board, known as the Roosevelt Board after its senior member, H. L. Roosevelt, concluded that "the Bureau system provides a satisfactory and efficient organization for assisting the Secretary of the Navy in performing the manifold duties of the Navy Department." The report recommended no change in the existing Bureaus, but rather a certain redistribution of cognizance among the several Bureaus. It is interesting to note that the Bureau of Construction and Repair member, Captain (later Rear Admiral) W. G. DuBose, again proposed the amalgamation of his Bureau with the Bureau of Engineering, but could not obtain the agreement of the other Board members.

On 13 June 1939, Chairman Carl Vinson of the House Committee on Naval Affairs, forwarded to all Bureau Chiefs and various other flag officers, a proposal for reorganizing the Navy Department. Foremost among the features of this proposal was the establishment of an office of Naval Material to coordinate all industrial and material activities.[7] Such an office would have

combined all of the Bureaus, but this plan was almost unanimously opposed by those asked to comment.[8]

This then is the background leading up to the formation of the Bureau of Ships in 1940. Before discussing the developments that occurred just prior to that consolidation, a review of the history of personnel changes appears to be in order.

PERSONNEL HIGHLIGHTS

In the early days of this country naval constructors were civilians, employed in the Navy when and as needed. The first of these, Joshua Humphreys, was in charge of building UNITED STATES back in 1794, and concurrently was designated "Principal Constructor of the Navy." As such he was the chief technical adviser to Benjamin Stoddert, the first Secretary of the Navy.

Likewise the first engineers were civilians. On 12 July 1836, Secretary Mahlon Dickerson appointed C. H. Caswell chief engineer of the steamship *Fulton the Second,* then under construction. Thus, Caswell became the first engineer in the Navy. In February 1842, Secretary Abel P. Upshur reported to Congress that he had no authority to enlist engineers, stating ". . . they can be employed only under some other name. Their pay is unascertained and dependent on private contract, and their rank in the service, and their position in the ship, are equally undetermined." Accordingly, on 31 August 1842, Congress authorized a corps of engineers, with an engineer-in-chief drawing an annual salary of $3,000 a year. Also a requisite number of chief and assistant engineers, "not to exceed eight for each steamship," was authorized. The first engineer-in-chief was Gilbert L. Thompson, a lawyer, scholar and diplomat. It has been said that "his engineering was purely nominal and confined to a very prompt and efficient drawing of his salary."

The Corps of Naval Engineers started out with about 35 members[9], but it was not until January 1859 when they numbered about 175, that they were authorized "assimilated" rank. This was the result of concerted efforts on the part of all the staff corps to obtain what they considered just recognition. When the Bureau of Steam Engineering came into existence in 1862, the first Engineer-in-Chief was Benjamin F. Isherwood who was largely responsible for the formation of the American Society of Naval Engineers a quarter of a century later.

Although the Act of 31 August 1842, in authorizing the Bureau of Construction, Equipment and Repair definitely called for a "skillful naval constructor" to be the Chief of Bureau, it was not until the Act of 3 March 1853 reiterated this requirement that the first naval constructor, Samuel Hart, became Chief of Bureau. The Secretary's explanation for his non-compliance with the 1842 law was that he preferred as Chief a Line officer qualified to equip, rather than a constructor qualified to construct and repair[3]. It was not until 25 July 1866 that naval constructors were granted "relative" rank (a term which replaced the previous "assimilated" rank). In passing it should be mentioned that despite many concerted efforts it was not until Josephus Daniels became Secretary of the Navy under President Wilson that the Staff Corps were permitted to use the rank titles; at the same time he abolished the characteristic color markings that had always distinguished the uniform of Staff Corps officers from that of the Line, and in lieu of the star used by the Line he substituted miniature corps devices.

Even after the Construction Corps was formed in 1866, its members were drawn from civilian life; they were

men who had had experience in practical naval architecture and shipbuilding. It was almost 20 years later before the first Naval Academy graduates, Francis T. Bowles and Richard Gatewood of the Class of 1881, were commissioned in the Construction Corps. On the other hand the members of the Engineer Corps were much closer to the Line; they were mainly graduates of the Naval Academy and, being seagoing personnel, they were living in day-to-day contact with their Line contemporaries. At the same time there was still prevalent in the Line a strong resentment against the change from sailing ships to steam-propelled ships. These factors were largely responsible for a considerable amount of friction between the Line and the Engineer Corps—much more so than between the Line and the other Staff Corps.

The differences between the Line and the Engineer Corps reached such proportions that on 4 November 1898, Secretary John D. Long appointed a Naval Personnel Board to study the problem. This Board, which was composed of Assistant Secretary Roosevelt and nine naval officers, five of the Line and four of the Staff, recommended the amalgamation of the two groups. A law amalgamating the Engineer Corps with the Line was enacted on 3 March 1899.

Even within the following decade there was much controversy as to the success of this 1899 amalgamation. In 1909, in connection with proposals to amalgamate Naval Constructors and Paymasters with the Line, the Secretary of the Navy stated that the excellent manner in which the Atlantic Fleet was maintained during its voyage around the world was an absolute demonstration of the wisdom of consolidation. Again in 1911[10] Secretary Meyer cited the "conspicuous success" of the 1899 amalgamation as reason for abolishing the Construction Corps and the Supply Corps. On the other hand the first note of doubt appears in a General Board letter[11] of 1909, which states "it appears to the Board that the only question for the future is how to create a small body of designing engineers from Line officers . . . . The present condition of the service affords no adequate and reliable means of obtaining a supply of such officers."

Likewise the annual reports of the Chief of the Bureau of Steam Engineering during the decade following the passage of the 1899 Act indicated that the Act did not solve the personnel problem. In the 1900 report[12] Admiral Melville had this to say, "Another year of experience under the provisions of the present bill finds the status of Steam Engineering interests in the Navy even less fully protected, and the number and condition of the forces for their control even less satisfactory than when I made my last annual report. To any close observer it is convincingly evident that either the scheme was a *mistake*, or that the proper course has not been taken to carry out its intent." Again in 1904 the annual report stated, "The problem which confronts us is this: how are we to obtain properly trained engineers when the present supply of officers so trained is exhausted?"

In 1916, the momentum of the old Engineer Corps was exhausted due to death and retirements. Realizing that existing procedures were not adequately providing for technical officers and recognizing the need for specialists, Congress passed a law on 29 August 1916, authorizing the selection of officers for Engineering Duty Only (EDO). The intimately detailed steps leading up to the passage of that Act are covered in the 1951 staff article in the Journal [2].*

Let us return to the Naval Constructors. As indicated above, there was

* Also see Secretary's Notes, this issue, p. 6.

considerable effort expended in 1909-11 to consolidate the Construction Corps and the Supply Corps with the Line. Although recommended by the Secretary[10], such a step was opposed by the General Board[11]. On 10 November 1911 the Secretary appointed the Amalgamation Board, headed by Assistant Secretary Beckman Winthrop, to consider the details of consolidating these personnel. This Board made its report on 20 December 1911, following which an Act to effect the consolidation was proposed, but was never passed.

The question of abolishing the Construction Corps was again raised by Secretary Edwin Denby in February 1923. This time the proposal was to amalgamate the Civil Engineer Corps, as well as the Construction Corps and Supply Corps, with the Line, but it met with almost universal disapproval from the various offices and Bureaus of the Navy Department.

Although 65 officers were selected for Engineering Duty Only (EDO) in the four years following the passage of the Act of 29 August 1916, no further selections were made until 1928. This gap is definitely related to the 1923 movement to abolish the Construction Corps, inasmuch as there was a powerful move afoot to abolish all Corps and all specialization. This furor gradually subsided and on 11 May 1928 Congress passed an Act which permitted the selection of more EDO's. There was evidently a great concern over the exact status of such officers, with the result that Secretary Charles Francis Adams appointed a Board to study the problem and to submit recommendations to remedy unsatisfactory conditions. The Board, known as the Halligan Board, submitted its report on 11 July 1930[12], and its recommendations established a policy for the size of the EDO group and the source and selection of EDO's that held for the next ten years, and to a certain extent until today.

One final step prior to 1940 in the struggle to amalgamate the Construction Corps with the Line occurred in 1933. On 8 May of that year, Secretary Claude A. Swanson appointed a Board headed by Assistant Secretary H. L. Roosevelt to consider amalgamating all Staff Corps and the Marine Corps with the Line. However, the Board recommended against "the complete amalgamation of any Staff Corps with the Line."

THE STATUS IN 1939-1940

This then is the background for the formation of the Bureau of Ships and the consolidation of the EDO's and the Naval Constructors. As should readily be evident, the agitation for Bureau and personnel amalgamation was not something new in 1940—rather it appears to have been an issue raised almost with every change in Secretary of the Navy since the middle of the last century.

In June 1940 the Bureau of Engineering had on board 71 officers and 449 civilians, while in the Bureau of Construction and Repair there were 46 officers and 541 civilians. Accordingly, the new Bureau of Ships started off with 117 officers and approximately 1,000 civilian employees, making it the largest by far of the various Navy Department Bureaus. Compare this with the 4 civilian employees in the Bureau of Construction, Equipment and Repair back in 1842, or with the total number of employees in the entire Navy Department of 151 in 1881 and 293 in 1897![3] Or compare it with the Bureau of Ships figures for June 1945—3,810 civilians and 1,477 officers!

When the two groups of naval personnel were combined in June 1940, 82 "engineering" EDO's joined 214 Naval

Constructors to form a Bureau of Ships EDO group of 296. These 296 individuals are listed in Appendix I, and it is interesting to note that 105 were still on active duty in August 1953. Of these, 10 were of the original "engineering" EDO group while 95 were ex-Naval Constructors. The large preponderance of the latter group is due to the fact that with an earlier career point for designation, the Construction Corps had a much larger percentage of its personnel in the junior ranks. Construction Corps officers began their technical training two years after graduation from the Naval Academy, whereas the EDO officers were selected after about 15 years of Line service.

THE BUREAU MERGER

The actual consolidation of the Bureau of Engineering and the Bureau of Construction and Repair stemmed from a letter dated 11 August 1939, from Acting Secretary of the Navy Charles Edison to the two Bureaus.[14] This letter is quoted in its entirety:

> "1. It is hereby directed that there be established within the Bureaus of Construction and Repair and Engineering a consolidation of the existing separate design divisions of the two Bureaus.
>
> "2. It is further directed that the Bureaus submit to the Acting Secretary of the Navy for his approval an administrative plan for effecting this consolidation not later than September 1, 1939."

What was behind this directive?

In the century of operations of the Navy Department since the first Bureaus were established, the Navy of necessity became more and more complex. This complexity resulted in the assignment to the various Bureaus over the years of functional jurisdictions which in many cases were controversial. In turn there resulted much overlapping and duplication of work, and at the same time inter-Bureau discords. This situation was particularly true of the Bureau of Engineering and the Bureau of Construction and Repair, the two Bureaus having the major responsibility for the design, construction and maintenance of ships.

The General Board succinctly described the cognizance problem in its Report No. 446, dated 12 January 1940[15] when it stated:

> ". . . Cognizance in general was based largely on traditional, rather than on logical considerations. In the gradual evolution of the two Bureaus, the distinction, or rather, the dividing line between 'hull'—the ship as a whole—and 'machinery'—boiler and engine—had become increasingly obscure. Whereas 'machinery' originally was confined to a relatively small and readily defined space in a ship, machines soon began to spread abroad, steam was essential outside the 'machinery' spaces, and electricity, represented once by a dynamo and a few incandescent lights—now pervades the ship. The 'hull' with its sails and spars and rigging, into which guns could be placed with as much ease as boats in their cradles, and in which steam propulsion was a reluctantly accepted auxiliary, has lost its character as a container of guns and engines and boilers and is an intricately mechanized unit into which armor, armament, propulsion, and mechanical and electrical power are built as constituent features of an integral whole. This development has been gradual and has permitted of certain organizational adjustments as among hull designers on the one hand and machinery designers on the other. These working agreements and compromises, in which all parties, including ordnance engineers, have had a share, have become increasingly dif-

ficult as mechanization of ships has increased, until the Navy finds itself, in respect to shipbuilding, in a position somewhat analogous to the building trades where jurisdictional overlaps serve to cause useless delays and financial loss.

". . . While the Board finds that the basic functions—designing the ship, building her, fitting her out, and keeping her in an effective state of repair to meet operating requirements—were dealt with in a somewhat similar manner in the two Bureaus . . . and that there were no inherent defects in the internal organization of either of the Bureaus, the continued attempt to deal with what is essentially an integral mechanized unit by differentiating between what constituted hull and hull appurtenances and what constituted machinery and machinery appurtenances set up such difficulties and formed the source of such delays as to warrant taking measures to remove the cause."

One other factor added to the seriousness of the controversy between the two Bureaus. As the European situation deteriorated in the 30's, shipbuilding in this country assumed increasingly large proportions. As the size of the new construction programs increased, the lack of coordination over the various phases of shipbuilding assumed greater significance. Delays in completion of ships,[16] [17] which might have been expected regardless of Bureau organization after two decades of shipbuilding famine, focused attention on the differences between the two Bureaus. Because of the lack of a coordinating head over the shipbuilding Bureaus, Assistant Secretary Edison was appointed Coordinator of Shipbuilding on 20 October 1938. But this did not solve the problem. In the words of Assistant Secretary Edison:[18]

"Early in the Spring of 1939 there became apparent a lack of cooperation between the Bureau of Construction and Repair and the Bureau o Engineering. As this lack of cooperation seemed to be based rather on personalities than on organization, I made an endeavor to make certain changes but was prevented from doing so because the Chief of Naval Operations and the Director of Shore Establishments advised the Secretary of the Navy to the contrary. This clash between the two principal shipbuilding Bureaus was brought to the surface and to my attention through a difference of opinion concerning the use of higher pressure and temperature steam conditions in the main machinery installations in the new ships.

"Later on in the Spring of 1939 I received unofficial word that one of the new destroyers had failed to successfully pass her inclining test, indicating a deficiency in her reserve stability. This matter came officially and formally to my attention in July 1939. . . . Here was a glaring example of the lack of coordination and cooperation between the Bureaus responsible for the construction of a ship, and also an example of the need for a change in organization and procedures which would preclude the possibility of a condition of this kind."

As to the first of the differences of opinion mentioned by Mr. Edison, the Bureau of Engineering had installed high-pressure, high-temperature machinery in the new destroyers of the *Mahan* class, and decided to use even higher temperature and pressure for destroyers in later programs. This decision resulted in a major controversy, principally between the Bureau of Engineering and certain private shipbuilders, and between the Bureau of Engineering and the Board of Inspection and Survey. The exact role of the Bureau of Construction and Repair in this controversy is not entirely clear although any Bureau differences appear

to have been insignificant as compared with the part played by the Board of Inspection and Survey.

The stability question was quite another matter. On 2 April 1939, *Anderson* (DD411), the first of a new class of destroyers, was inclined and the results of the inclining experiment indicated that she was overweight by some 150 tons, as compared with the design displacement. Also her metacentric height in the light condition was considerably below that of earlier destroyers. A second inclining experiment was conducted from which comparable results were obtained.[19] Analysis of the data indicated that the overweight could not be attributed to material under the cognizance of a single Bureau. Rather, with the exception of about 9 tons of ordnance material, it was divided almost equally between the Bureau of Construction and Repair and the Bureau of Engineering.

This incident of the so-called "top heavy" destroyers was immediately picked up by the newspapers, with the result that press reports greatly magnified the defects in this class of destroyers. The public was given the impression that the ships would turn over any time, whereas in actual fact the stability condition was just not up to the usual Navy standards, but was readily improved to closely approach those standards. But the damage was done. The public exerted heavy pressure on Congress for reform in the organization of the Navy Department, and there was a major controversy in the Department over who was responsible for the overweight condition.

In his letter of 3 January 1940 to Chairman Walsh of the Senate Naval Affairs Committee, Secretary Edison stated that he considered the Bureau of Construction and Repair primarily to blame because that Bureau was responsible for the general design and stability of naval ships.[20, 21] However, the Bureau of Construction and Repair, while admitting that responsibility, claimed that the organization of the Department did not vest in the Bureau the requisite full authority to meet such responsibility, and that the blame should have been shared by three activities—the Bureau of Construction and Repair, the Bureau of Engineering, and the contractor through its design agent, Gibbs and Cox.

Regardless of who was to blame, two facts were quite evident. First, subsequent to the adoption of the *Anderson* design, treaty limitations had been removed, and there was a natural inclination on the part of all concerned to stress reliability and ruggedness rather than lightness in weight. Second, more effective coordination between the two Bureaus should be provided.

Secretary Edison's first step to obtain better Bureau coordination was to issue the above-quoted directive[14] to consolidate the separate design divisions. The reader will note that this directive also told the two Bureaus to submit an administrative plan for effecting this consolidation. Apparently there was a difference of opinion between the two Bureau Chiefs, Rear Admiral W. G. DuBose (Construction and Repair) and Rear Admiral H. G. Bowen (Engineering),* as to whether a joint Bureau plan or separate Bureau plans should be submitted[22, 23]; at any rate they actually submitted two separate plans. A memorandum prepared by Admiral DuBose is quoted in full[24]:

> "1. Paragraph 2 of the Secretary's order of August 11, 1939, directed that a plan for effecting the consolidation of the design divisions within the Bureaus of Construction and Repair,

* Rear Admiral Bowen's 4 year appointment as Chief of the Bureau of Engineering had actually expired in May 1939. From then until September 1939 he was serving as Chief in an interim status pending the appointment of a new Chief.

and Engineering, be submitted for approval of the Acting Secretary of the Navy not later than 1 September 1939. This order was not complied with for the following reasons:

"On Tuesday, 29 August, about 11 o'clock, Admiral Bowen brought to the office of the Chief Constructor a plan for consolidation that had been prepared in the Bureau of Engineering. At that time a corresponding plan that had been prepared in the Bureau of Construction and Repair was shown to Admiral Bowen. As neither plan was satisfactory to the other Bureau officer, the suggestion was made that a conference be held with the Acting Secretary of the Navy to discuss the question.

"This conference was held on the morning of the 30th of August, at which time—following a general discussion of the main features of the two plans—copies of each, together with a pencil diagram showing the main differences between the two were left with the Acting Secretary of the Navy. He stated that it appeared desirable to take about two weeks more to consider the matter.

"Nothing further was heard until Admiral S. M. Robinson on Friday, September 1st (?) showed the Chief Constructor a copy of an order which he had received from the Acting Secretary of the Navy appointing a Board (of which he was Senior Member) to consider and make recommendations in the premises."

On 31 August 1939, Secretary Edison appointed a Board to review the plans submitted by the two Bureau Chiefs. This Board was headed by Rear Admiral (later Admiral) Samuel M. Robinson, and included Captain Lewis B. McBride (CC), Commander (later Vice Admiral) Edward L. Cochrane (CC), and Commander (later Rear Admiral) Paul F. Lee. The promptness with which the Secretary took this action, plus the last paragraph of Admiral DuBose's memorandum quoted above, led to the conclusion that this Board was appointed without consulting either of the two Bureau Chiefs.

The Board, in its report dated 12 September 1939, while agreeing that consolidation of the two design divisions was desirable, did not consider that such a consolidation was sufficient.[25] The Board recommended a complete unification and consolidation of the two Bureaus, pointing out that otherwise there would be a potentially difficult situation wherein the new design division would be responsible to two co-equal but independent superiors.

Admiral Robinson gives the credit for this recommendation and its subsequent approval to Captain McBride. He recently had this to say about Captain McBride and the meetings of the Board[26]:

"From the time when he was a young Lieutenant he started preaching the doctrine of a single Bureau. Of course, few people paid any attention to him most of the time. But he was a most persistent, persuasive talker; also he was very bright and very popular. As the years went by, opportunities seemed to arise that offered some hope and he was always 'Johnny-on-the-spot' with his plans but they always went wrong and it finally began to look as if Mac would never make it—especially since his health had become steadily worse. But I am sure that Mac never really gave up hope and finally his opportunity really came and he grasped it so quickly, so firmly and so completely that it never had a chance to get away.

". . . I am perfectly certain that the day we met he had his plans all fully perfected but he said nothing about them. We discussed the prob-

lem of a common Design Division at great length. In fact we worked long hours because the Secretary was in a hurry. So was Mac. In order to lose no time, we continued our discussions at luncheon but after two or three days when I announced an adjournment for luncheon, I found the other three members all had some excuse for not going out so I went out by myself. If I had been psychic I am sure I would have realized that something was up because the members' excuses seemed rather thin after I had looked back on them. At any rate when I returned, I found that Mac had held a caucus and proposed that we recommend a complete amalgamation of the two Bureaus; his reason for excluding me from the proceedings also became apparent. He proposed that I should be made Chief of both Bureaus pending legislation to unite them. He further proposed that we proceed immediately to see the Secretary and make these recommendations.

". . . We immediately marched up to the Secretary's office and Mac laid the whole thing before him. I am sure the Secretary was as much astonished as I had been and his first remark was—'You have exceeded your precept, haven't you?' A gross understatement if I ever heard one. However if he had known Mac as well as I did he would have realized that precepts meant very little to him. We harassed the Secretary for several hours and it was finally agreed to go ahead with the plan and immediately at that. He sent for the Judge Advocate General and told him to make up two Commissions for me to be sent to the President and we struck the first snag. The Judge Advocate General said this was illegal. That did not bother Secretary Edison very much. He had become enthusiastic and promptly solved this problem by giving me additional duties as Coordinator of Shipbuilding—a position the Secretary held himself at that time. That, of course, solved any questions of over-all authority . . ."

The following day (13 September) Admiral Robinson reported to the Secretary of the Navy as Chief of the Bureau of Engineering. On 14 September Admiral Robinson was also appointed Coordinator of Shipbuilding. On 18 September Rear Admiral A. H. Van Keuren became Chief of the Bureau of Construction and Repair, as relief for Admiral DuBose. Three days later Admiral Van Keuren received the additional appointment as Assistant Coordinator of Shipbuilding.

On 27 September 1939, Secretary Edison authorized the two Bureau Chiefs to arrange their personnel and offices in such manner as would give the most efficient operation of the two Bureaus. The organization manual promulgated by the two Chiefs on 5 October set up four principal Divisions, viz., Design, Production, Maintenance and War Plans. Administrative matters were assigned to five officers reporting to the office of the Coordinator of Shipbuilding—Administrative Assistant, Contracts, Personnel, Financial and General Inspector. Two days later the Contracts Office was abolished and a Contracts Section established in the Production Division.

A SINGLE BUREAU

Thus, early in October 1939 the Bureau of Engineering and the Bureau of Construction and Repair were consolidated—i.e., they were consolidated as far as it was possible to go by administrative action under existing law. Nevertheless they were not a single Bureau, but rather two Bureaus with legally assigned cognizances and responsibilities and acting under separate appropria-

tions. They still were required to maintain complete documentary records of inter-Bureau transactions and to issue directives to field activities and letters to other agencies over joint signatures of both Bureaus.

While Admiral Robinson and Admiral Van Keuren were proceeding to take the preliminary steps necessary to consolidate the work of the two Bureaus, the interested authorities in the Navy Department and in Congress were considering legislation for complete merger of these Bureaus. Unfortunately this legislation had rough sledding because it contained many other provisions for Navy Department reorganization not pertinent directly to the two Bureaus. As has been mentioned previously, Chairman Vinson of the House Naval Affairs Committee made certain proposals for reorganizing the Navy Department on 13 June 1939,[27] which proposals would have, in effect, combined all the Material Bureaus. The General Board, in commenting on the proposed Bill, recommended retaining the Bureau system and favored combining the Bureau of Construction and Repair and the Bureau of Engineering into a single Bureau to be known as the Bureau of Ships.[27] The Secretary of the Navy, in commenting on the Vinson proposal, came up with a new thought.[28] Secretary Edison proposed the establishment of a Chief of Shore Operations, who would have duties and responsibilities for the industrial shore establishment comparable to those of the Chief of Naval Operations in the operation of the Fleet. In his letter to the Bureau of the Budget, on 29 February 1940, Secretary Edison included this proposal (although the title of the new position had become "Director of Shore Activities"), along with one to form the new Bureau of Ships.[29] It was these two proposals which formed the basis of Congressional hearings that commenced on 26 February 1940, and continued intermittently until 19 April 1940, with the provision concerning the Office of Shore Activities being by far the more controversial item. There was actually almost unanimous approval on the part of the various Navy Department activities concerned, for the formation of the Bureau of Ships.[15, 27, 30, 31, 32, 33, 34 and 35]

After the first month of Congressional hearings the proposed Office of Shore Activities met a quick demise upon receipt by Acting Secretary Lewis Compton on 3 April 1940, of the following memorandum quoted in full, from President Roosevelt [36]:

> "(1) I think there must be some mistake in regard to the suggested Naval Reorganization Bill. Before the Secretary of the Navy left I made certain matters extremely clear.
>
> "I am willing to accept (a) a clause to legalize the Bureau of Ships with a Rear Admiral at its head under a status similar to that of other Bureau Chiefs, together with two assistants, one of whom may carry the rank of Rear Admiral where the Chief of the Bureau of Ships belongs to the other branch of the service. In other words, if the Bureau Chief is a Constructor, he may have as an assistant an Engineering Officer or vice versa.
>
> "(b) A clause to create an Under Secretary of the Navy with such duties as the Secretary shall assign to him.
>
> "(c) Language making it clear that C.N.O. can control priorities where such priorities relate to Navy Yard work on operating naval vessels or naval vessels out of commission or in reserve which C.N.O. determines shall be put into the status of full commission.
>
> "Outside of these, which I made very clear at least three weeks ago, I want no other legislation.

"For your own information and that of the Secretary in regard to the setting up of an office of shore establishments, it is my desire that this part of Navy work, i.e., material, shall be handled by the Assistant Secretary of the Navy, this duty being assigned to him by the Secretary. I have no objection to having detailed to him any Officer or Officers of any rank desired to carry out supervision of shore establishment work."

Bill H.R. 8921, introduced by Mr. Darden of the House Naval Affairs Committee on 13 March 1940, contained the item regarding the Office of Shore Activities. This Bill was superseded on 8 April 1940 by H.R. 9266, also introduced by Mr. Darden and containing instead the provision for establishing the Under Secretary of the Navy. Senator Walsh introduced the companion Bill, S. 4026, on 22 May 1940. Despite the modification in scope, the Bills still carried the title "Bill providing for the Reorganization of the Navy Department."

After the House hearings were finally completed, two or three members of the Naval Affairs Committee signed a minority report which in effect prevented the presentation of the Bill on the floor of the House. At this point Senator Walsh told Admiral Robinson that if the latter could get all interested activities in the Navy Department to come before his Committee and agree to the House Bill without changing a single word, then Senator Walsh believed he could get the Bill through the Senate.[36] After a little behind-the-scenes quibbling, this was accomplished. The Senate passed the Bill in short order, but only after Senator Walsh persuaded another member of the Senate not to object to the "grandiose" title of the Bill. With the Senate's approval of the Bill which was word for word like the House Bill, Mr. Vinson took the latter on the floor of the House where it passed without objection. It should be mentioned at this point that during the various preparatory stages of the legal consolidation of the Bureau, both within the Navy Department and during the time the bill was up before Congress, Rear Admiral DuBose was tireless in his "missionary" efforts in favor of the merger. Although this may appear to be strange, since he had been relieved as Chief of the Bureau of Construction and Repair, it was simply the culmination of thirty years of effort on his part toward the consolidation, as has been inferred in connection with his participation in the Anderson Board[55] and the Roosevelt Board.[6]

The Bill establishing the Bureau of Ships was approved on 20 June 1940, becoming Public Law No. 644, 76th Congress.[37] Other than the personnel question, which will be discussed below, only one more action remained to be taken. That was the transfer of certain cognizant functions from other Bureaus to the Bureau of Ships. On 20 June 1940, the Secretary directed the transfer of the cognizance of equipage and supplies relating to the maintenance and operation of ships from the Bureau of Navigation and Bureau of Supplies and Accounts, and the transfer of the cognizance of consumable ordnance supplies from the Bureau of Ordnance. This action became effective on 1 July 1940.

During the course of the hearings the subject of transferring the cognizance of armor plate from the Bureau of Ordnance to the Bureau of Ships was raised several times. Although Rear Admiral W. R. Furlong, Chief of the Bureau of Ordnance, was strongly opposed to such a transfer, Secretary Edison directed that the Bureau of Ships assume the cognizance of armor plate. But after the Chief of Naval Operations and Mr. Vinson objected, President Roosevelt overrode the directive of the Secretary on 24 June 1940.

THE MERGER OF PERSONNEL

Although, as has been indicated, the Bill merging the two Bureaus was not passed overnight, there was little opposition to the formation of the Bureau of Ships. Even one of the Chiefs of the two Bureaus concerned expressed his strong concurrence in the idea.[30] However, there was far from unanimity of opinion with regard to the question of what to do with the two groups of personnel—the Constructors and the EDO's.

As will be discussed below, most officials in high positions in the Navy Department were in favor of combining the two groups of officer personnel into one specialist group, although there were differences of opinion as to whether this specialist group should be a Staff Corps or part of the Line. However, many officers, particularly those in the Construction Corps below the rank of Captain wanted to retain the Construction Corps in its then existing form. This desire undoubtedly stemmed from an intense *esprit de corps,* with its dislike for abolishing a corps which through its almost century-long existence had attained high prestige both in this country and abroad. Typical of the feelings of these officers were those expressed by the lieutenants of the Construction Corps on duty in the Navy Department.[38] They objected to the argument of the "opposition" that efficiency would be increased by amalgamating the officer personnel, pointing out that the Industrial Departments of the Navy Yards had been operating for over twenty years with Constructors and EDO's working side by side or for each other, depending upon rank and position. However, the recommendation for retaining the Construction Corps and the EDO's was overruled by those in authority.

Once it was decided to merge the two groups into one technical body there was considerable controversy as to whether the Constructors should become EDO's, or whether the EDO's should join the Constructors in a new staff corps. The majority of the Bureau of Engineering EDO's favored the first course, while the majority of the Constructors favored the latter. The arguments for each cause were stated as follows:[35, 39 and 40]

Advantages of a Line status

(1) Closer relationships with the Line of the Navy.

(2) More favorable probabilities of promotion, as judged by past selections. Since the EDO's were extra numbers the "Line fraction" was not applied to them in selection for promotion, i.e., they were selected on their own merits. On the other hand the Construction Corps was subject to the "Line fraction" and in order to avoid "passing over" a relatively large number of officers Constructors were being selected several years after their Line contemporaries. (It is interesting to note that during the first selections after the Constructors were put back in the Line, several were "passed over." Whether their non-selection was based solely on their records, or whether the selection boards arbitrarily applied the "Line fraction" is of course not known, but at the time many ex-Constructors believed the latter to be true.)

(3) A greater number of rear admirals among the Constructors. In June 1940 there were 8 rear admirals in the EDO group and only 2 rear admirals in the Construction Corps. Actually that corps was allowed only one permanent rear admiral plus a temporary rear admiral as the Chief of the Bureau, if the officer filling that position was not the permanent rear admiral.

(4) Improvement of morale in that officers would not be selected for promotion several years after their Line contemporaries.

(5) Simplification of duty assignments, particularly where close relationship with Line officers is involved.

(6) Broader application of rights to command and to succession to command.

Advantages of a Staff Corps status

(1) Increased chances of retention of prestige in the naval architecture and marine engineering professions.

(2) Selection boards would be made up of technical officers familiar with the relative worth of the eligibles.

(3) Possibility of attracting more young officers specially fitted for technical work.

The Robinson Board,[25] in recommending the merger of the two Bureaus, also recommended that the Construction Corps and the EDO's be unified into a single technical group, but did not express a preference for either Line or Staff Corps status. Rear Admiral DuBose expressed the same point of view in his letter to the Secretary on 12 September 1939,[30] as did Rear Admirals Robinson and Van Keuren in their joint letters of 26 September [30] and 27 October.[31] In other words the Bureau Chiefs recommended the amalgamation of the two groups of officers into a single technical group, with common treatment, common prospects, and common basic training for the younger officers entering this group; but they left the decision to higher authority as to how the merger should take place.

It so happened that the Staff Corps Personnel Board, headed by Rear Admiral E. J. King,[41] was in session at this time, and the Secretary referred the question to that Board. In its report, dated 9 December 1939, the majority (6 members) of the Board favored transferring the EDO's into a Staff Corps called the "Line Technical Corps." But three (3) members submitted a minority report in which they recommended giving the Constructors a Line status. In its report [15] on the merger of the two Bureaus, the General Board noted the majority and minority recommendations of the King Board, agreed that the personnel ought to be merged, but did not arrive at any conclusion as to whether a Line status or a Staff Corps status was preferred. Finally in his letter to Senator Walsh,[21] Secretary Edison noted that he had received the King Board report but stated "I have not yet had the opportunity to form my own conclusions."

Accordingly, in February 1940, the question was unsettled. At this point Rear Admiral Van Keuren, believing that an early merger of personnel was of prime necessity, told the Secretary that he favored merging of the Constructors with the EDO's on the basis of the existing EDO system. This recommendation from the Chief Constructor paved the way for an agreement between all activities concerned, and resulted in the drafting of a personnel bill giving the Naval Constructors a Line status. Admiral Van Keuren's statement in this respect, given before the House Naval Affairs Committee on 25 April 1940,[40] is quoted as follows:

> ". . . I adopted this course as being the best and simplest solution of the controversial personnel question and in the interest of harmony and efficiency of the combined Bureaus and the service as a whole. I took this step knowing all the implications thereof and all the heart-burnings of many members of my Corps, only after careful consideration and consultation with groups of officers of various ranks in the Bureau. I believe it to be to the eventual good of the members of the Corps, as well as of the service as a whole . . . I am aware that my views are not

shared by some members of my own Corps, particularly the younger members thereof, but it has never been possible to obtain unanimity of opinion on personnel questions. Therefore, it is my considered opinion that the present time, in view of the consolidation of the Bureaus and of the field forces into combined organizations, is ripe for the amalgamation of the two bodies of officers rather than some future time when the questions may be obscured by other considerations. I know that I have the support of many members of the Corps and am willing to assume the responsibility of recommending this Bill."

Admiral Robinson has stated that he did not have any definite conviction as to whether a Line status or a Staff Corps status was the better answer,* but felt that there could be no "quick" amalgamation unless a Line status was decided upon. But because of the large number of individuals who favored a Staff Corps status, he unofficially promised many of the senior Naval Constructors with whom he talked that after a short trial period of a year or two he would initiate a move to transfer the EDO's into a Staff Corps if any considerable number of the ex-Naval Constructors still wanted to take such a step. Admiral Robinson has recently told the author that he never found a single ex-Constructor who wanted to go back into a Staff Corps.

On 18 April 1940, Mr. Vinson of the House Naval Affairs Committee introduced Bill H.R. 9450 which provided for the merger of the Construction Corps with the EDO's. Hearings were held starting 25 April and continuing until 7 May. On 22 May Senator Walsh introduced Bill S. 4027 which was a companion Bill to H.R. 9450. Hearings were held between 16 May and 23 May. These Bills were approved on 25 June 1940, becoming Public Law No. 657, 76th Congress.[43]

THE BUREAU OF SHIPS, 1940-1953

Congress having approved the new Bureau, Rear Admiral Robinson became the first Chief of the Bureau of Ships on 21 June 1940. On the same date Rear Admiral Van Keuren became Assistant Chief of the Bureau of Ships. Admirals Robinson and Van Keuren were also given additional duty as Coordinator of Shipbuilding and Assistant Coordinator of Shipbuilding, respectively. With the passage of Public Law No. 657, the members of the Construction Corps were transferred to the Line as EDO's, and were given the precedence they would have had if they had originally remained in the line.

Public Law 644 specifies that the Chief and Assistant Chief of the Bureau of Ships are to be appointed "from among the officers of the active list of the Navy who are specially qualified and experienced in naval engineering or naval architecture." The law further provides that if the Chief is specially qualified and experienced in naval engineering, the Assistant Chief must be qualified in naval architecture and vice versa. Since its origin the Bureau has had 7 Chiefs—4 Engineers and 3 Ex-Constructors. These are listed, together with all the Chiefs of the Bureau of Engineering and Bureau of Construction and Repair, in Appendix II.

As has been mentioned above, the Bureau started off with 117 officers and approximately 1,000 civilians. It was organized somewhat along the lines of the October 1939 organization of the combined Bureaus. There were five main Divisions, Administrative, Design, War Plans, Shipbuilding and Maintenance, with fiscal matters being handled by the Administrative Division, contractual matters by the Shipbuilding

* As late as September 1953 he has stated that he still has no firm conviction in this regard.

Division, and research matters by the Design Division. Electronics was then a branch, known as the Radio and Sound Branch, within the Design Division.

This then was the Bureau organization in August 1940. As the war effort expanded the Bureau of necessity adjusted its organization almost continually, to take care of the varying requirements of the Fleet. The first major change was the elimination of the War Plans Division in September 1941, when the preparation for war had reached such a stage that war plans became major operating responsibilities of the other Bureau Divisions.

Within the first year after Pearl Harbor, three further changes were made. Fiscal matters were removed from the Administrative Division and assigned to a new Finance Division. The increasing importance of electronics in the Navy resulted in setting up a Radio Division. Finally, the Shipbuilding and Design Divisions were combined into a new Shipbuilding Division which consisted of a Design Branch, a Contract Branch and a Construction Branch.

No other major changes were made until June 1944 when the Contract Division was established. Then in the Spring of 1945 the Shipbuilding and Maintenance Divisions were combined, and a new Shore Division was established. Finally, research functions were transferred to a new Research Division. This organization is substantially the one that exists today.

One final episode in the history of the Bureau deserves to be mentioned. With the unification of the Services and the start of the Korean episode, the Chief of the Bureau was delegated the responsibility for coordinating repairs and conversions within the Department of Defense and with other Government agencies during wartime or during national emergencies. This occurred on 15 February 1951.

NAVAL SHIPYARDS

The development of today's Naval Shipyards is intimately tied up with the history of the Bureau of Ships and its officer personnel. Before 1861 there was a tendency toward an extension of the Bureau system into the Navy Yards. Each Bureau had its own shops, supply system, powerhouse, etc. Then in the 1880's Secretary Whitney consolidated under a single storekeeper, stores that were used by two or more Bureaus. Succeeding Secretaries instituted further consolidations, as for example the combining of all powerhouses in 1904. In 1909 Secretary Newberry tried to place all shop activities under the Bureau of Construction and Repair, but without success. Then in 1921 the Navy Yard Division was established under the Assistant Secretary of the Navy. However, while this Division was theoretically responsible for the work of the various Navy Yards, it did not function as such if for no other reason than that it had no control over the funds assigned to the yards.

Prior to the formation of the Bureau of Ships the officer in charge of each Navy Yard was a Line officer known as the Commandant. Under him, in charge of industrial work, was a Manager, who was either an EDO or a Constructor. The Manager looked to all the technical Bureaus, particularly the Bureaus of Engineering and of Construction and Repair, for funds and technical guidance, but he had no control over such supporting functions as supply and operations which were accomplished by other co-equal department heads each reporting directly to the Commandant. The formation of the Bureau of Ships greatly simplified the responsibilities of the Navy Yard Managers, but

still left them without control of the above subsidiary or service functions contributing to the industrial effort. This was the organization in effect throughout World War II.

Because of the inefficiencies inherent in the existing organization and administration of Navy Yards, Secretary James Forrestal, with the support of Fleet Admiral E. J. King and Vice Admiral E. L. Cochrane (Chief of the Bureau of Ships), directed a study of this matter by the Inspector General, Admiral C. P. Snyder, in March 1945. Admiral Snyder's report of this study recommended certain sweeping changes in Navy Yard organization and in departmental administration of the yards.[44] These changes, which were approved,[45, 46 and 47] involved:

(1) The centralization of the internal management and technical control of the industrial activities in the hands of an officer trained and experienced in industrial management;

(2) The concentration of adequate authority for departmental administration in a single agency of the Navy Department—the Bureau of Ships; and

(3) The integration of logistic activities in the locality of each Navy Yard under a single military command—the Base Commander.

Accordingly there was established in the area of each of the old Navy Yards a Naval Base, which included all Naval shore activities in the vicinity. As one of the component commands of each Naval Base, there was also established a Naval Shipyard, under the command of an officer technically trained in the building and repairing of ships and possessing substantial experience in the management phases of such work. Each Shipyard Commander was assigned the necessary authority over all the various support functions (supply, accounting, medical, operations and public works) required to support the shipyard's mission.

The one weakness of the new shipyard set-up was the lack of complete control by the management Bureau (i.e. Bureau of Ships) of the financial support of shipyard operations. But with the advent of the "performance budget" in 1950 this control was considerably strengthened.

PERSONNEL 1940-1953

For several decades prior to 1940 prospective Naval Constructors were normally Naval Academy graduates who after two years of sea duty as Line officers were sent to Massachusetts Institute of Technology for a three-year course in naval construction.* During or on completion of the course they were transferred to the Construction Corps, and on graduation they started on a Naval Constructor career involving duty in Navy Yards, the Bureau, etc. They were assigned comparatively little sea duty, and that was either on staffs afloat or on tenders and repair ships.

At the same time prospective Bureau of Engineering EDO's were drawn from a group of Line officers who stayed on sea duty after graduation from the Naval Academy for six or seven years, whereupon they were ordered to the Naval Postgraduate School at Annapolis for a course in naval engineering (design). The course was either a two- or three-year course, part of which was spent at the PG School and part at a civilian college such as Columbia University or the University of California. After graduation they returned to sea duty and

* For a comprehensive account of the early training of Naval Constructors the reader is referred to reference (1).

some were designated EDO after about 15 years commissioned service, while the remainder continued their careers as unrestricted Line officers.

With the merger of the Constructors and EDO's and the desire to train future additions to the new EDO group on substanitally the same basis, it was decided to institute a combined course in naval architecture and marine engineering at MIT to replace the old naval construction course. The plan for recruiting the new EDO's was:

(1) Officers would be selected for postgraduate training after two years at sea.

(2) After this selection these officers would continue for a third year at sea in engineering assignments on large ships.

(3) On completion of the third year at sea, they would enter MIT.

(4) After completion of the 3-year course at MIT, they would be designated EDO, and ordered to a Navy Yard for two years.

(5) They would spend the 9th and 10th years on sea duty.

This plan went into effect in the Fall of 1940. The first group of officers to take the combined course (dubbed the "Congineer" course; its graduates have been called "Congineers" to differentiate them from the Constructors and the EDO's trained under the old systems) were of the Naval Academy Class of 1937. As of 1940, the junior Bureau of Engineering EDO was in the Class of 1925, and the junior graduates of the naval engineering (design) course at the PG School were of the Classes of 1930 or 1931. Accordingly, it was realized that provisions would have to be made for continuing the naval engineering (design) course until all Naval Academy classes prior to that of 1937 had been afforded an opportunity for such training, and for continuing the designation as EDO's of certain graduates of that course. Although, as indicated, this continuation of technical postgraduate training in naval engineering was originally considered as an interim measure,[48] it has become evident during recent years that there is a continuing need for ED officers with broad engineering experience afloat, as well as for Congineers.[49]

A brief examination of the two courses (Congineer and Naval Engineer) appears to be in order. When the Congineer course first started in 1940 all of the students took exactly the same course. This procedure continued until 1946, with its graduates obtaining additional specialization only by means of additional education, of a year's duration, or by other duty assignments.

In 1946 when the Congineer Class of 1949 commenced their postgraduate work, the course was broken up into various specialties. For the next three years the following specialty courses were given:

Hull design and contruction
Ship propulsion engineering
Marine electrical engineering
Nuclear engineering
Ship habitability
Internal combustion engines
Hydraulic machinery, propellers and lubrication.

Three years later the specialties were reduced to the first four of the above, plus electronics engineering. The following year (1950), starting with the Congineer Class of 1953, the nuclear engineering specialty was eliminated and the course contained only four specialties:

Hull design and construction
Ship propulsion engineering
Marine electrical engineering
Electronics engineering

For the past four years the Congineer course has been limited to these four

specialties. Of the 19 officers commencing the course in 1953, 8 were assigned to hull design and construction, 3 to marine electrical engineering, and 4 each to the other two specialties. In addition, starting in 1950, 4 officers have been sent each year to Webb Institute for a course in hull design and construction.

The naval engineering (design) course from 1940 to 1948 was very similar to what it had been previously, except it varied in length from 18 months to 3 years and in most cases the full course was taken at the PG School. Then in 1948 mechanical engineering and electrical engineering, under the broad course title of "naval engineering," were made full 3-year courses at the PG School. Likewise electronics engineering was a full 3-year course at the PG School. However, the other specialties of naval engineering, e.g., diesel engineering, metallurgical engineering, and chemical engineering, were overed by one year at the PG School and two years at a civilian university.

In 1951 the naval engineering course was abolished, in line with a new policy of redesignating the curricula to agree with the practices of civilian educational institutions. Thus mechanical engineering, electrical engineering, electronics engineering, petroleum engineering, etc., all became separate courses of two or three years' duration.

The Engineering Duty Officer group as presently constituted consists of four types of officers:

(1) Former Engineering Duty Only officers who were recruited from the Line after approximately 15 years of service, plus similar officers designated since 1940.

(2) Former naval Constructors.

(3) Congineers.

(4) Naval Reserve Officers with an engineering background who transferred to regular Navy after World War II. Many of these officers have been given a one year's "equalization" course at the PG School, while some have had the 3-year Congineer's course.

Controversy concerning the Line status of ED officers did not end with the passage of Public Law No. 657 on 25 June 1940. Early in January 1941, a special Board convened to study the status of Line officers designated for special duty, made its report.[50] This Board consisted of two members, Mr. Lewis Compton, Assistant Secretary of the Navy, and Rear Admiral Joseph M. Reeves, USN, Retired. After a lengthy discussion regarding the combatant duties of Line officers, the Board recommended transferring EDO's into two staff corps, viz., Construction Corps and Marine Engineer Corps. Nothing came of this Board's report.

As a result of experiences during World War II, indicating the need for additional Line specialists to perform the Navy's functions in such fields as law, intelligence and communications, there was considerable pressure exerted at the end of the War toward combining all such specialists plus the EDO's and AEDO's into one combined staff corps. A Board was appointed in 1945 to study this subject, but in its report it recommended the continuance of the EDO and AEDO groups, and the establishment of an SDO group to cover the other specialties.[51] The following year another Board studying the entire officer personnel situation recommended that all such specialists be part of the Line, but that they all be called Special Duty Officers, with additional letter designation to indicate such particular specialties as engineering and aeronautical engineering.[52]

The report of the last mentioned Board led to the passage of the Officer Personnel Act of 1947.[53] However, that Act, which, with its latest amendments, is the governing law for the existing

ED officer set-up, did not amalgamate Engineering Duty Officers with the other Line specialties. One feature of that Act of importance to this article was the discontinuance of the designation "EDO" and the substitution of "ED" in its place. In other words, the expression "Engineering Duty Only," which was distinctive only by restriction, was done away with. The officers previously designated EDO officers became ED officers, i.e. Engineering Duty officers.

The most recent Board to study the ED officer structure, reaffirmed the continuance of the ED group as a distinctive Line specialty.[54]

IN RETROSPECT

In the final paragraph of its report the Robinson Board[25] made the following statements:

> "Unquestionably some objections to the above proposals will develop from individuals. We are unanimously of the conviction, however, that the advantages to be gained in this case transcend any individual personnel difficulties which conjecture may develop and that the fundamental benefit to the Navy is of such outstanding promise as to outweigh any such considerations."

One might well ask if the two mergers, Bureau and personnel, have been successful. The author considers that such a question would receive a unanimous affirmative answer. But a similar question inquiring into whether the mergers have been more successful than if the originally separate Bureaus and groups had never been merged, might not receive a unanimous answer.

Very few people will argue that had the Bureau of Engineering and Bureau of Construction and Repair continued in operation through World War II, their accomplishments would have been as efficient and as timely as were those of the Bureau of Ships. Anyone familiar with the time and effort involved in Joint Bureau of Ships-Bureau of Ordnance operations during the War, would realize that the much greater volume of matters pertaining jointly to hull and machinery would have imposed a tremendous burden on shipbuilding and ship repair operations under a two-Bureau set-up.

However, the personnel question is another matter. There are undoubtedly some ED officers who still believe that the operations of the Bureau of Ships would have been just as successful if its officer personnel were still of two separate groups. Perhaps this belief will still continue until the last of the members of the original EDO and Naval Constructor groups has left active service. However the author believes that most of the senior ED officers agree with Vice Admiral E. L. Cochrane, USN, Retired, a former Naval Constructor and wartime Chief of the Bureau of Ships, who, in testifying before the Dyer Board[55] in 1945, had this to say:

> "... Personally, I was very proud of the fact that I was a member of the Construction Corps, and I opposed to the best of my feeble effort the consolidation of that group into the Line. My own firm conviction today is that that opposition was a mistake. The position which the ED officer holds is an important one. It unquestionably has facilitated the psychology, the responsibility and acceptance of this group as a two-way affair. Our response to the Line's requirements and the Line's acceptance of what we have done, both have been improved by that arrangement."

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(3) "A Brief History of the Organization of the Navy Department," by Captain A. W. Johnson, USN, Navy Paper No. 284, 76th Congress.

(4) "An Administrative History of the Bureau of Ships During World War II," published by the Bureau of Ships, 1952.

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(6) Report of a Board to consider and recommend upon the reorganization of the Navy Department, and the amalgamation of certain or all staff corps and the Marine Corps with the Line of the Navy, dated 6 November 1933 (Roosevelt Board).

(7) Chairman, House Naval Affairs Committee letter to all Chiefs of Bureaus and certain other flag officers, date 13 June 1939.

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(9) "A Study of the Basic Objectives in The Post Graduate Education of Naval Aviators," by Captain Walter S. Diehl, USN, published by the Bureau of Aeronautics, May 1950.

(10) Secretary of the Navy letters to Chairmen of Committees on Naval Affairs, House and Senate, dated 19 June 1911.

(11) General Board letter, G. B. No. 421, dated 17 May 1909.

(12) Chief, Bureau of Yards and Docks memorandum to Chief of Naval Operations, dated 26 February 1923.

(13) Report of a Board to study and submit recommendations looking to the formulation of a policy regarding officers designated for the performance of engineering duty only, dated 11 July 1930 (Halligan Board).

(14) Acting Secretary of the Navy letter EN/A3-1(390811) of 11 August 1939 to the Bureau of Engineering and the Bureau of Construction and Repair.

(15) Chairman, General Board letter G. B. No. 446, Serial No. 1906, to the Secretary of the Navy, dated 12 January 1940.

(16) Memorandum from President F. D. Roosevelt to Assistant Secretary Edison dated 16 March 1938.

(17) Assistant Secretary of the Navy memorandum to President F. D. Roosevelt, dated 1 April 1938.

(18) Secretary of the Navy memorandum for file "History of Reorganization Effort," dated 16 December 1939.

(19) Memorandum from Commander H. N. Wallin, (CC) USN, to Captain A. J. Chantry, (CC) USN, dated 17 August 1939.

(20) Chairman, Senate Naval Affairs Committee letter to Acting Secretary of the Navy, dated 5 December 1939.

(21) Acting Secretary of the Navy letter to Chairman, Senate Naval Affairs Committee, dated 3 January 1940.

(22) Memorandum from Rear Admiral W. G. DuBose, (CC) USN, to Rear Admiral H. G. Bowen, USN, dated 21 August 1939.

(23) Memorandum from Rear Admiral H. G. Bowen, USN, to Rear Admiral W. G. DuBose, (CC) USN, dated 22 August 1939.

(24) Memorandum from Rear Admiral W. G. DuBose, (CC) USN, for file, dated 6 September 1939.

(25) Report of Board convened by the Secretary of the Navy to review the organization charts submitted by the Chief of the Bureau of Construction and Repair, and the Chief of the Bureau of Engineering, dated 12 September 1939.

(26) Speech by Admiral S. M. Robinson, USN, Retired, on 8 July 1953, printed in August 1953 issue of THE JOURNAL OF AMERICAN SOCIETY OF NAVAL ENGINEERS.

(27) Chairman, General Board letter to the Secretary of the Navy dated 5 December 1939, commenting on proposed reorganization bill dated 13 June 1939.

(28) Secretary of the Navy letter EN/A3-1(390613) of 3 January 1940 to Chairman, House Naval Affairs Committee.

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(30) Memorandum from Rear Admiral W. G. DuBose, (CC) USN, to Secretary of the Navy, dated 12 September 1939.

(31) Joint memorandum, Rear Admirals Robinson and Van Keuren to Admiral Stark, dated 27 October 1939.

(32) Joint Bureau of Engineering and Bureau of Construction and Repair memorandum to the Secretary of the Navy, dated 20 January 1940.

(33) Hearing before Special Subcommittee on the Reorganization of the Navy Department, 26 February to 8 March 1940 (No. 313 Revised).

(34) Hearing before House Committee on Naval Affairs on the Reorganization of the Navy Department, 16-19 April 1940 (No. 350).

(35) Hearings before the Senate Committee of Naval Affairs on S4026 (H.R. 9266), Reorganization of the Navy Department, and S4027 (H.R. 9450), Transfer of Construction Corps to the Line, 16-23 May 1940.

(36) Memorandum from President F. D. Roosevelt to Acting Secretary of the Navy, dated 3 April 1940.

(37) Act of 20 June 1940, Public Law 644, 76th Congress.

(38) Statement regarding H.R. 9450 by lieutenants of Construction Corps on duty in Navy Department, undated (Spring of 1940).

(39) Joint Bureau of Construction and Repair and Bureau of Engineering letter, BUCON No. EN/A3-1&2(c), BUENG No. P16-3/00(9-26), to Chief of Bureau of Navigation dated 26 September 1939.

(40) Statement by Rear Admiral A. H. Van Keuren at hearings on H.R. 9450, 25 April 1940.

(41) Report of the Board convened by the Secretary of the Navy to investigate and report upon the distribution, promotion, retirement, etc., of staff corps and officers designated for Engineering Duty Only and for Aeronautical Engineering Duty Only, dated 9 December 1939 (King Board).

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(43) Act of 25 June 1940, Public Law 657, 76th Congress.

(44) "Review of the Organization and Administration of Navy Yards and U. S. Naval Drydocks," submitted on 13 July 1945 to the Secretary of the Navy by Admiral C. P. Snyder, USN.

(45) Secretary of the Navy letter, subject "Reorganization of Navy Yards and Establishment of Naval Bases," dated 14 September 1945.

(46) General Order No. 223 dated 14 September 1945.

(47) General Order No. 19 dated 20 May 1949.

(48) Joint Bureau of Engineering and Bureau of Construction and Repair letter, BUCON No. 00-(1), EN/A3-1&2, BUENG No. P16-3/00(9-26-0), to Staff Corps Personnel Board dated 1 December 1939.

(49) Report of Board to study and recommend on matters pertaining to Engineering Duty Officers, dated 18 July 1951 (Leggett Board).

(50) Report of the Board convened by the Secretary of the Navy to investigate and report upon all matters concerning the status of Line Officers designated for specialized duties, date 3 January 1941 (Compton Board).

(51) Report of a Board to submit comments and recommendations on the proposed formation of a Navy technical corps, dated 30 November 1945 (Dyer Board).

(52) Report of a Board to recommend a postwar program for promotion and retirement and a plan for the adjustment of lineal position in the Regular Navy and Marine Corps, upon termination of temporary appointments, dated 15 March 1946 (Low Board).

(53) Act of 7 August 1947 (Officer Personnel Act of 1947), Public Law 381, 80th Congress.

(54) Report of a Board to study the Engineering Duty, Aeronautical Engineering Duty, and Special Duty Officer structure, dated 24 March 1953 (Low Board).

(55) Report of the Navy Department Reorganization Board, dated 30 July 1921 (Anderson Board).

APPENDIX I

ORIGINAL BUREAU OF SHIPS EDO GROUP

Rear Admiral William G. DuBose, Constructor, Class of 1897, Retired 1940. Ex-Chief of the Bureau of Construction and Repair.
Rear Admiral Henry Williams, Constructor, Class of 1898, Retired 1941. President of the Society, 1940.
Rear Admiral Paul B. Dungan, Engineer, Class of 1899, Retired 1941. Died 1941.
Captain William McEntee, Constructor, Class of 1900, Retired 1940, Died 1946.
Rear Admiral Ivan E. Bass, Engineer, Class of 1901, Retired 1941.
Rear Admiral Julius A. Furer, Constructor, Class of 1901, Retired 1944.
Rear Admiral Charles W. Fisher, Jr., Constructor, Class of 1901, Retired 1944.
Captain Isaac I. Yates, Constructor, Class of 1901, Retired 1945.
Captain Clayton M. Simmers, Constructor, Class of 1902, Retired 1943.
Captain John W. Woodruff, Constructor, Class of 1902, Retired 1942, Died 1944.
Captain Edwin G. Kintner, Constructor, Class of 1902, Retired 1945.
Admiral Samuel M. Robinson, Engineer, Class of 1903, Retired 1946. Ex-Chief of the Bureau of Engineering; ex-Chief of the Bureau of Ships; President of the Society, 1931 and 1939; Secretary-Treasurer of the Society, 1921-1923.
Rear Admiral Alexander H. Van Keuren, Constructor, Class of 1903, Retired 1945. Ex-Chief of the Bureau of Construction and Repair; Ex-Deputy Chief and Ex-Chief of the Bureau of Ships.
Rear Admiral Roy W. Ryden, Constructor, Class of 1903, Retired 1946.
Captain Ross P. Schlabach, Constructor, Class of 1903, Retired 1943. Died 1951.
Rear Admiral Herbert S. Howard, Constructor, Class of 1904, Retired 1946. President of the Society, 1942.
Rear Admiral Harry A. Stuart, Engineer, Class of 1904, Retired 1943. Died 1950.
Vice Admiral Harold G. Bowen, Engineer, Class of 1905, Retired 1947. Ex-Chief of the Bureau of Engineering; President of the Society, 1938.
Rear Admiral Ormand L. Cox, Engineer, Class of 1905, Retired 1946. Secretary-Treasurer of the Society, 1913, 1928, 1931.
Rear Admiral Albert T. Church, Engineer, Class of 1905, Retired 1943. Secretary-Treasurer of the Society, 1915-1916.
Rear Admiral Stanford C. Hooper, Engineer, Class of 1905, Retired 1943.
Captain Lee S. Border, Constructor, Class of 1905, Retired 1945.
Captain James O. Gwane, Constructor, Class of 1905, Retired 1943.
Captain Halford R. Greenlee, Engineer, Class of 1905, Retired 1940.
Captain Arthur K. Atkins, Engineer, Class of 1905, Retired 1940.
Captain Alva B. Court, Constructor, Class of 1905, Retired 1941.
Rear Admiral Allan J. Chantry, Constructor, Class of 1906, Retired 1946.
Captain Lew M. Atkins, Constructor, Class of 1906, Retired 1947.
Captain Hollis M. Cooley, Engineer, Class of 1906, Retired 1946.
Captain Claude A. Bonvillian, Engineer, Class of 1906, Retired 1946.
Rear Admiral Charles A. Dunn, Engineer, Class of 1907, Retired 1947.
Rear Admiral Bryson Bruce, Engineer, Class of 1907, Retired 1946. Secretary-Treasurer of the Society, 1924-1925.
Rear Admiral Claud A. Jones, Engineer, Class of 1907, Retired 1946, Died 1948. Ex-Deputy Chief of the Bureau of Ships; President of the Society, 1941.
Captain Philip G. Lauman, Constructor, Class of 1907, Retired 1943.
Captain Ralph T. Hanson, Constructor, Class of 1907, Retired 1946.

Captain Joseph S. Evans, Engineer, Class of 1907, Retired 1947. Secretary-Treasurer of the Society, 1919-1921.
Captain Philip H. Hammond, Engineer, Class of 1907, Retired 1943.
Captain Edmund D. Almy, Engineer, Class of 1907, Retired 1943.
Captain Baxter H. Bruce, Engineer, Class of 1907, Retired 1944, Died 1950.
Rear Admiral Alexander M. Charlton, Engineer, Class of 1908, Retired 1946. Secretary-Treasurer of the Society, 1926.
Rear Admiral Joseph J. Broshek, Engineer, Class of 1908, Retired 1946. President of the Society, 1943.
Rear Admiral James M. Irish, Engineer, Class of 1908, Retired 1946.
Rear Admiral Albert M. Penn, Engineer, Class of 1908, Retired 1945, Died 1947.
Rear Admiral Frank J. Wille, Engineer, Class of 1908, Retired 1947.
Rear Admiral Timothy J. Keleher, Engineer, Class of 1908, Retired 1943.
Captain Edmund R. Norton, Constructor, Class of 1908, Retired 1943.
Captain Henry F. D. Davis, Engineer, Class of 1908, Retired 1947. Secretary-Treasurer of the Society, 1932.
Captain Charles C. Ross, Engineer, Class of 1908, Retired 1940, Died 1953.
Captain David F. Ducey, Engineer, Class of 1908, Retired 1947.
Captain Frederic T. Van Auken, Engineer, Class of 1908, Retired 1946.
Captain Harry G. Donald, Engineer, Class of 1908, Retired 1947.
Rear Admiral Harold T. Smith, Engineer, Class of 1909, Retired 1946. Secretary-Treasurer of the Society, 1929-1930.
Rear Admiral Thomas B. Richey, Constructor, Class of 1909, Retired 1944, Died 1949.
Rear Admiral Claude S. Gillette, Engineer, Class of 1909, Retired 1946. Secretary-Treasurer of the Society, 1935-1936.
Rear Admiral Sherman S. Kennedy, Engineer, Class of 1909, Retired 1948.
Rear Admiral Charles L. Brand, Constructor, Class of 1910, Retired 1949, Died 1953. President of the Society, 1944.
Rear Admiral Roger W. Paine, Engineer, Class of 1911, Retired 1949. President of the Society, 1948; Secretary-Treasurer of the Society, 1936-1938.
Captain Lybrand P. Smith, Engineer, Class of 1911, Retired 1942, Died 1948.
Captain Ernest L. Patch, Constructor, Class of 1911, Retired 1946.
Captain Harold E. Saunders, Constructor, Class of 1912, Retired 1949.
Rear Admiral Frederick G. Crisp, Constructor, Class of 1913, Retired 1947.
Captain Everett L. Gayhart, Constructor, Class of 1913, Retired 1943.
Captain Earl F. Enright, Constructor, Class of 1913, Retired 1944.
Captain Palmer H. Dunbar, Jr., Engineer, Class of 1913, Retired 1943.
Captain Wilbur J. Ruble, Engineer, Class of 1913, Retired 1947.
Captain Henry A. Seiller, Engineer, Class of 1913, Died 1944.
Vice Admiral Edward L. Cochrane, Constructor, Class of 1914, Retired 1947. Ex-Chief of the Bureau of Ships.
Commodore Adrian R. Marron, Constructor, Class of 1914, Retired 1947.
Captain Gordon W. Nelson, Constructor, Class of 1914, Retired 1947.
Captain Joseph L. McGuigan, Constructor, Class of 1914, Retired 1949.
Captain Fred M. Earle, Constructor, Class of 1914, Retired 1946.
Captain John I. Hale, Constructor, Class of 1914, Retired 1947.
Captain William E. Malloy, Engineer, Class of 1914, Retired 1949.
Vice Admiral Howard L. Vickery, Constructor, Class of 1915, Died 1946.
Rear Admiral Claude O. Kell, Constructor, Class of 1915, Retired 1950.
Commodore Robert N. S. Baker, Constructor, Class of 1915, Retired 1948.

Captain Gerard H. Wood, Engineer, Class of 1915, Retired 1946.
Commander Melville W. Powers, Constructor, Class of 1915, Retired 1942.
Lieutenant Commander Glenn H. Easton, Constructor, Class of 1915, Retired 1941.
Rear Admiral Grover C. Klein, Constructor, Class of 1916, Retired 1951.
Rear Admiral Thorvold A. Solberg, Engineer, Class of 1916, Retired 1951. President of the Society, 1949.
Commodore Webster M. Thompson, Engineer, Class of 1916, Retired 1947.
Captain Sidney E. Dudley, Constructor, Class of 1916, Retired 1947.
Captain Russell S. Hitchcock, Constructor, Class of 1916, Retired 1949.
Rear Admiral Frederic E. Haeberle, Constructor, Class of 1917, Retired 1951. President of the Society, 1950.
Rear Admiral Norborne L. Rawlings, Constructor, Class of 1917, Retired 1947.
Rear Admiral Homer N. Wallin, Constructor, Class of 1917. Ex-Chief of the Bureau of Ships; President of the Society, 1953.
Rear Admiral Andrew I. McKee, Constructor, Class of 1917, Retired 1947.
Commodore Edmund E. Brady, Jr., Constructor, Class of 1917, Retired 1948.
Commodore Lisle F. Small, Engineer, Class of 1917, Retired 1947.
Captain Theodore L. Schumacher, Constructor, Class of 1917, Retired 1949, Died 1952.
Captain Douglas W. Coe, Constructor, Class of 1917, Retired 1947.
Commander George K. Weber, Engineer, Class of 1917, Retired 1942.
Vice Admiral Earle W. Mills, Engineer, Class of 1918, Retired 1949. Ex-Deputy Chief and Ex-Chief of the Bureau of Ships; President of the Society, 1945.
Rear Admiral Joseph W. Fowler, Constructor, Class of 1918, Retired 1948.
Captain William J. Malone, Constructor, Class of 1918, Retired 1949.
Captain Ralph S. McDowell, Constructor, Class of 1918, Retired 1949.
Captain John D. Crecca, Constructor, Class of 1918, Retired 1948.
Captain William C. Wade, Constructor, Class of 1918, Retired 1949.
Captain William R. Nichols, Constructor, Class of 1918, Retired 1947.
Captain Owen E. Grimm, Engineer, Class of 1918, Retired 1947.
Commander Ernest B. Colton, Engineer, Class of 1918, Retired 1941.
Rear Admiral Thomas P. Wynkoop, Jr., Constructor, Class of 1919, Retired 1949.
Rear Admiral Louis Dreller, Engineer, Retired 1951. President of the Society, 1951.
Rear Admiral David H. Clark, Engineer, Class of 1919, Retired 1953. Ex-Chief of the Bureau of Ships; President of the Society, 1951.
Rear Admiral Paul F. Lee, Engineer, Class of 1919, Retired 1948.
Rear Admiral William A. Sullivan, Constructor, Retired 1948.
Rear Admiral William W. Hastings, Constructor, Retired 1947.
Commodore George T. Paine, Constructor, Retired 1947.
Captain Paul W. Hains, Constructor, Class of 1919, Retired 1949.
Captain James G. McPherson, Constructor, Retired 1946.
Captain Frederick B. Britt, Constructor, Retired 1945.
Captain Charles H. Cushman, Constructor, Class of 1919, Retired 1947.
Captain Harry L. Dodson, Engineer, Retired 1948.
Captain Roy W. Bruner, Engineer, Retired 1949.
Captain Duane L. Taylor, Engineer, Retired 1947.
Captain Roger F. McCall, Engineer, Retired 1947.
Captain Antonio S. Pitre, Constructor, Class of 1919, Retired 1949.
Captain Winfield A. Brooks, Engineer, Class of 1919, Retired 1949.
Captain Adolph O. Gieselmann, Engineer, Class of 1919, Retired 1949.
Captain James E. J. Kiernan, Constructor, Class of 1919, Retired 1947.

Captain Richard McK. Rush, Constructor, Class of 1919, Retired 1947.
Captain Joseph M. Kiernan, Constructor, Retired 1946.
Captain Noah W. Gokey, Constructor, Retired 1950.
Captain Hubert K. Stubbs, Engineer, Retired 1946.
Captain Robert Velz, Constructor, Retired 1941.
Captain Thomas F. O'Brien, Constructor, Died 1942.
Captain Irving B. McDaniel, Constructor, Retired 1947.
Captain Harold Larner, Constructor, Retired 1947.
Captain George W. Henderson, Constructor, Retired 1950.
Captain Gerald W. Thomson, Constructor, Retired 1944.
Captain Wendell P. Roop, Constructor, Retired 1947.
Commander Albert G. Merrill, Constructor, Retired 1941.
Commander Herbert Duthie, Constructor, Retired 1941.
Commander John H. Jack, Jr., Constructor, Retired 1941.
Commander Charles Hibbard, Constructor, Retired 1941.
Lieutenant Commander Joseph J. Redington, Constructor, Retired 1941.
Lieutenant Commander Tony L. Hannah, Constructor, Retired 1941, Died 1947.
Rear Admiral E. W. Sylvester, Constructor, Class of 1920. President of the Society, 1953-4.
Rear Admiral Paul B. Nibecker, Constructor, Class of 1920.
Rear Admiral Roy T. Cowdrey, Constructor, Class of 1920.
Rear Admiral Wesley Mc. Hague, Constructor, Class of 1920.
Rear Admiral Wallace R. Dowd, Constructor, Class of 1920.
Rear Admiral Hugh E. Haven, Engineer, Class of 1920.
Rear Admiral Edgar P. Kranzfelder, Engineer, Class of 1920, Retired 1950.
Commodore Jennings B. Dow, Engineer, Class of 1920, Retired 1947.
Captain Horatio C. Sexton, Constructor, Class of 1920, Retired 1950.
Captain Lawrence T. Haugen, Constructor, Class of 1920, Retired 1948.
Captain Walter F. Christmas, Constructor, Class of 1920, Retired 1950.
Captain Dewitt C. Redgrave, Jr., Constructor, Class of 1920, Retired 1950.
Captain Philip Lemler, Constructor, Class of 1920, Retired 1948.
Captain Roswell B. Daggett, Constructor, Class of 1920, Retired 1950.
Captain Floyd A. Tusler, Constructor, Class of 1920, Retired 1947.
Captain James H. Chadwick, Engineer, Class of 1920, Retired 1949.
Captain Benjamin P. Ward, Engineer, Class of 1920, Retired 1950.
Rear Admiral Ralph E. McShane, Constructor, Class of 1921.
Rear Admiral Charles D. Wheelock, Constructor, Class of 1921, Retired 1953. Ex-Deputy Chief of the Bureau of Ships.
Rear Admiral Richard M. Watt, Jr., Constructor, Class of 1921.
Rear Admiral Wilson D. Leggett, Jr., Engineer, Class of 1921. Ex-Deputy Chief and present Chief of the Bureau of Ships.
Rear Admiral Logan McKee, Engineer, Class of 1921.
Captain William E. Sullivan, Engineer, Class of 1921, Died 1950. Was selected for promotion to Rear Admiral but died before promotion.
Captain Robert K. Wells, Constructor, Class of 1921, Died 1949.
Captain James E. Hamilton, Engineer, Class of 1921, Retired 1951, Secretary-Treasurer of the Society, 1940-1944 and 1949-Present.
Captain Edward E. Roth, Engineer, Class of 1921, Retired 1951.

Captain William R. Millis, Engineer, Class of 1921, Retired 1952.
Captain Guy Chadwick, Engineer, Class of 1921, Retired 1951. Secretary-Treasurer of the Society, 1938-1940.
Captain William J. Murphy, Constructor, Class of 1921, Retired 1952.
Captain William H. Magruder, Constructor, Class of 1921, Died 1952.
Captain Joseph C. Huske, Constructor, Class of 1921, Retired 1951.
Captain Carl S. Drischler, Engineer, Class of 1921, Retired 1943, Died 1944.
Lieutenant Commander Mortimer E. Serat, Jr., Constructor, Class of 1921, Retired 1940, Died 1949.
Rear Admiral Leslie A. Kniskern, Constructor, Class of 1922.
Rear Admiral Bernard E. Manseau, Constructor, Class of 1922. Present Deputy Chief of the Bureau of Ships.
Rear Admiral Hyman G. Rickover, Engineer, Class of 1922.
Captain Leonard Kaplan, Constructor, Class of 1922, Retired 1949.
Captain John A. Sweeten, Constructor, Class of 1922, Retired 1947.
Captain Francis A. Whitaker, Constructor, Class of 1922, Retired 1953.
Captain Dale Quarton, Constructor, Class of 1922, Retired 1952.
Captain Henry A. Ingram, Constructor, Class of 1922, Retired 1953.
Captain Edward C. Craig, Constructor, Class of 1922, Retired 1953.
Captain Leland D. Whitgrove, Constructor, Class of 1922, Retired 1953.
Captain Milo R. Williams, Constructor, Class of 1922.
Captain Edward C. Forsyth, Engineer, Class of 1922, Retired 1953.
Captain William B. Holden, Engineer, Class of 1922, Retired 1947.
Rear Admiral George A. Holderness, Jr., Constructor, Class of 1923.
Rear Admiral Peter W. Haas, Jr., Engineer, Class of 1923.
Commodore Henry A. Schade, Constructor, Class of 1923, Retired 1949.
Captain Robert C. Bell, Constructor, Class of 1923, Died 1952.
Captain Emmett E. Sprung, Constructor, Class of 1923, Retired 1953.
Captain Fred W. Walton, Engineer, Class of 1923. Secretary-Treasurer of the Society, 1945-1948.
Captain Pleasant D. Gold, Engineer, Class of 1923.
Captain Marshall M. Dana, Engineer, Class of 1923, Retired 1947.
Captain Homer Ambrose, Engineer, Class of 1923.
Lieutenant Commander William S. Kurtz, Constructor, Class of 1923, Died 1941.
Rear Admiral Armand M. Morgan, Constructor, Class of 1924.
Rear Admiral Edward V. Dockweiler, Constructor, Class of 1924, Retired 1949.
Captain Wendell E. Kraft, Constructor, Class of 1924.
Captain John J. Scheibeler, Constructor, Class of 1924.
Captain LeRoi B. Blaylock, Engineer, Class of 1924, Retired 1947.
Captain Max Schreiner, Engineer, Class of 1924.
Captain Harry Burris, Engineer, Class of 1924, Retired 1951.
Captain Schuyler N. Pyne, Constructor, Class of 1925. Selected for Rear Admiral in July 1953.
Captain Wilubr N. Landers, Constructor, Class of 1925, Retired 1947.
Captain Alexander Sledge, Constructor, Class of 1925.
Captain John H. Spiller, Constructor, Class of 1925.
Captain William C. Latrobe, Engineer, Class of 1925.

Commander Lingurn H. Burkhead, Constructor, Class of 1925, Retired 1947.
Lieutenant Commander Carlton H. Moore, Constructor, Class of 1925, Retired 1941, Died 1952.
Captain William W. Anderson, Jr., Constructor, Class of 1926, Died 1946.
Captain James H. Rodgers, Constructor, Class of 1926.
Captain Oscar Stiegler, Constructor, Class of 1926.
Captain Francis X. Forest, Constructor, Class of 1926.
Captain George C. Weaver, Constructor, Class of 1926.
Captain William C. Sprenger, Constructor, Class of 1926.
Captain Joseph L. Bird, Constructor, Class of 1926.
Captain Edmund M. Ragsdale, Constructor, Class of 1926, Retired 1948.
Captain John H. Ellison, Constructor, Class of 1926.
Captain Mario G. Vangeli, Constructor, Class of 1926.
Captain William T. Jones, Constructor, Class of 1926.
Captain Philip W. Snyder, Constructor, Class of 1927.
Captain Robert A. Hinners, Constructor, Class of 1927.
Captain Allan L. Dunning, Constructor, Class of 1927.
Captain Herbert J. Pfingstag, Constructor, Class of 1927.
Captain Herbert C. Zitzewitz, Constructor, Class of 1927.
Captain Robert D. Conrad, Constructor, Class of 1927, Retired 1947, Died 1949.
Captain Henry T. Koonce, Constructor, Class of 1927.
Captain Allen M. Zollars, Constructor, Class of 1927.
Captain Leroy V. Honsinger, Constructor, Class of 1927.
Captain William H. Leahy, Constructor, Class of 1927.
Captain John B. Smyth, Constructor, Class of 1927.
Captain Charles M. Tooke, Constructor, Class of 1927.
Captain Charles R. Watts, Constructor, Class of 1928.
Captain William E. Howard, Jr., Constructor, Class of 1928.
Captain Raymond O. Burzynski, Constructor, Class of 1928.
Captain Ralph K. James, Constructor, Class of 1928.
Captain Philip F. Wakeman, Constructor, Class of 1928.
Captain John Zabilsky, Constructor, Class of 1928.
Captain Victor B. Cole, Constructor, Class of 1928.
Rear Admiral John H. Keatley, Constructor, Class of 1929, Retired 1949.
Captain James M. Farrin, Constructor, Class of 1929.
Captain Leslie E. Richardson, Constructor, Class of 1929, Retired 1949.
Captain Herbert J. Hiemenz, Constructor, Class of 1929.
Lieutenant Commander Howard R. Garner, Class of 1929, Died 1943.
Captain Harold M. Heiser, Constructor, Class of 1930.
Captain Stanley M. Alexander, Constructor, Class of 1930.
Captain Oscar M. Browne, Jr., Constructor, Class of 1930.
Captain Robert E. Perkins, Constructor, Class of 1930.
Captain Robert T. Sutherland, Constructor, Class of 1930, Retired 1950. Secretary-Treasurer of the Society, 1945.
Captain Harry W. Englund, Constructor, Class of 1930.
Captain Marvin H. Gluntz, Constructor, Class of 1930.
Captain Richard K. Anderson, Constructor, Class of 1931.

Captain Ernest C. Holtzworth, Constructor, Class of 1931.
Captain Albert K. Romberg, Constructor, Class of 1931.
Captain Joseph E. Flynn, Constructor, Class of 1931.
Captain Edward A. Wright, Constructor, Class of 1931.
Commander John G. F. Prescott, Constructor, Class of 1931, Died 1945.
Commander Ransom A. Pierce, Constructor, Class of 1931, Retired 1942.
Captain Richard S. Mandelkorn, Constructor, Class of 1932.
Captain Floyd B. Schultz, Constructor, Class of 1932.
Captain William R. Miller, Constructor, Class of 1932.
Captain Charles J. Palmer, Constructor, Class of 1932.
Captain Paul W. Pfingstag, Constructor, Class of 1932.
Captain George W. Bailey, Constructor, Class of 1932.
Captain Robert L. Evans, Constructor, Class of 1932.
Lieutenant Charles J. Weschler, Constructor, Class of 1932, Died 1944.
Captain Robert B. Madden, Constructor, Class of 1933.
Captain Jack W. Roe, Constructor, Class of 1933.
Captain James S. Bethea, Constructor, Class of 1933.
Captain Henry P. Rumble, Constructor, Class of 1933.
Captain Charles A. Curtze, Constructor, Class of 1933.
Captain Robert E. Garrels, Constructor, Class of 1933.
Lieutenant Commander Allan Mc. Chambliss, Constructor, Class of 1933, Retired 1941.
Lieutenant Robert A. Gallagher, Constructor, Class of 1933, Died 1944.
Captain Charles H. Gerlach, Constructor, Class of 1934.
Captain Edgar H. Batcheller, Constructor, Class of 1934.
Captain Walter E. Baranowski, Constructor, Class of 1934.
Captain Edward R. Tilburne, Constructor, Class of 1934.
Captain George C. Wells, Constructor, Class of 1934.
Captain William W. Keller, Constructor, Class of 1934.
Captain Lewis L. Schock, Jr., Constructor, Class of 1935.
Captain John J. Fee, Constructor, Class of 1935.
Captain John H. McQuilkin, Constructor, Class of 1935.
Captain Benjamin G. Wade, Constructor, Class of 1935.
Captain Howard Z. Senif, Constructor, Class of 1935.
Captain Bradley F. Bennett, Constructor, Class of 1935.
Captain William F. Petrovic, Constructor, Class of 1935.
Captain Walter A. Moore, Jr., Constructor, Class of 1935.
Commander James A. Brown, Constructor, Class of 1936.
Commander Dale F. Pinkerton, Constructor, Class of 1936.
Commander James H. Terry, Jr., Constructor, Class of 1936.
Commander John B. Rawlings, Constructor, Class of 1936.
Commander Henry A. Arnold, Constructor, Class of 1936.
Commander Irwin J. Frankel, Constructor, Class of 1938.
Commander James J. Stilwell, Constructor, Class of 1938.
Commander John B. Shirley, Constructor, Class of 1938.
Commander James F. Ellis, Jr., Constructor, Class of 1938.

APPENDIX II

CHIEFS OF BUREAUS

BUREAU OF STEAM ENGINEERING

(later Bureau of Engineering)

B. F. Isherwood, *Engineer-in-Chief*
March 1861-March 1869
James W. King, *Engineer-in-Chief*
March 1869-March 1873
W. W. W. Wood, *Engineer-in-Chief*
March 1873-March 1877
W. H. Shock, *Engineer-in-Chief*
March 1877-June 1883
C. H. Loring, *Engineer-in-Chief*
January 1884-July 1887
G. W. Melville, *Engineer-in-Chief*
August 1887-August 1903
C. W. Rae, *Engineer-in-Chief*
August 1903-May 1908
John K. Barton, *Engineer-in-Chief*
June 1908-December 1908
Hutch I. Cone, *Engineer-in-Chief*
May 1909-May 1913
Robert S. Griffin, *Rear Admiral*
May 1913-September 1921
John K. Robison, *Rear Admiral*
October 1921-October 1925
John Halligan, Jr., *Rear Admiral*
October 1925-September 1928
H. E. Yarnell, *Rear Admiral*
September 1928-May 1931
Samuel M. Robinson, *Rear Admiral*
May 1931-May 1935
H. G. Bowen, *Rear Admiral*
May 1935-September 1939
Samuel M. Robinson, *Rear Admiral*
September 1939-June 1940

BUREAU OF CONSTRUCTION, EQUIPMENT AND REPAIR

(later Bureau of Construction and Repair)

Samuel Hart, *Chief Constructor*
July 1853-November 1853
John Lenthall, *Chief Constructor*
November 1853-January 1871
Isaiah Hanscom, *Chief Constructor*
January 1871-April 1877
John W. Easby, *Chief Constructor*
April 1877-December 1881
T. D. Wilson, *Chief Constructor*
March 1882-July 1893
Philip Hichborn, *Chief Constructor*
July 1893-March 1901
F. T. Bowles, *Chief Constructor*
March 1901-October 1903
W. L. Capps, *Chief Constructor*
October 1903-October 1910
Richard M. Watt, *Chief Constructor*
October 1910-December 1914
David W. Taylor, *Rear Admiral (CC)*
December 1914-July 1922
John D. Beuret, *Rear Admiral (CC)*
July 1922-November 1929
George H. Rock, *Rear Admiral (CC)*
November 1929-September 1932
Emory S. Land, *Rear Admiral (CC)*
September 1932-March 1937
William G. DuBose, *Rear Admiral (CC)*
March 1937-September 1939
Alexander H. Van Keuren,
Rear Admiral (CC)
September 1939-June 1940

BUREAU OF SHIPS

Samuel M. Robinson, *Rear Admiral*
June 1940-February 1942
Alexander H. Van Keuren,
Rear Admiral
February 1942-November 1942
Edward L. Cochrane, *Vice Admiral*
November 1942-November 1946
Earle W. Mills, *Vice Admiral*
November 1946-February 1949
David H. Clark, *Rear Admiral*
February 1949-February 1951
Homer N. Wallin, *Rear Admiral*
February 1951-July 1953
Wilson D. Leggett, Jr., *Rear Admiral*
July 1953-to date

APPENDIX III

ENGINEERING DUTY OFFICER SELECTIONS FOR FLAG RANK SUBSEQUENT TO MERGER

December 1940

Alexander H. Van Keuren, Constructor
Roy W. Ryden, Constructor
Herbert S. Howard, Constructor
Allan J. Chantry, Constructor

September 1941

Julius A. Furer, Constructor
Bryson Bruce, Engineer

September 1942

Claud A. Jones, Engineer
Alexander M. Charlton, Engineer
Joseph J. Broshek, Engineer
James M. Irish, Engineer
Harold T. Smith, Engineer
Thomas B. Richey, Constructor
Charles L. Brand, Constructor
Howard L. Vickery, Constructor

January 1943

Claude S. Gillette, Engineer
Sherman S. Kennedy, Engineer

June 1944

Frank J. Wille, Engineer
Albert M. Penn, Engineer
Frederick G. Crisp, Constructor
Timothy T. Keleher, Engineer
Edward L. Cochrane, Constructor

October 1945

Roger W. Paine, Engineer
Claude O. Kell, Constructor
Grover C. Klein, Constructor
Thorvold A. Solberg, Engineer
Frederick E. Haeberle, Constructor
Norborne L. Rawlings, Constructor

November 1946

Joseph W. Fowler, Constructor
Earle W. Mills, Engineer
Thomas P. Wynkoop, Jr., Constructor
Louis Dreller, Engineer
David H. Clark, Engineer
Paul F. Lee, Engineer
Evander W. Sylvester, Constructor
Paul B. Nibecker, Constructor

November 1947

Homer N. Wallin, Constructor
Roy T. Cowdrey, Constructor

December 1948

Wesley Mc. Hague, Constructor
Wallace R. Dowd, Constructor
Hugh E. Haven, Engineer

December 1949

Ralph E. McShane, Constructor
Charles D. Wheelock, Constructor
William E. Sullivan, Engineer

September 1950

Richard M. Watt, Jr., Constructor
Wilson D. Leggett, Jr., Engineer

July 1951

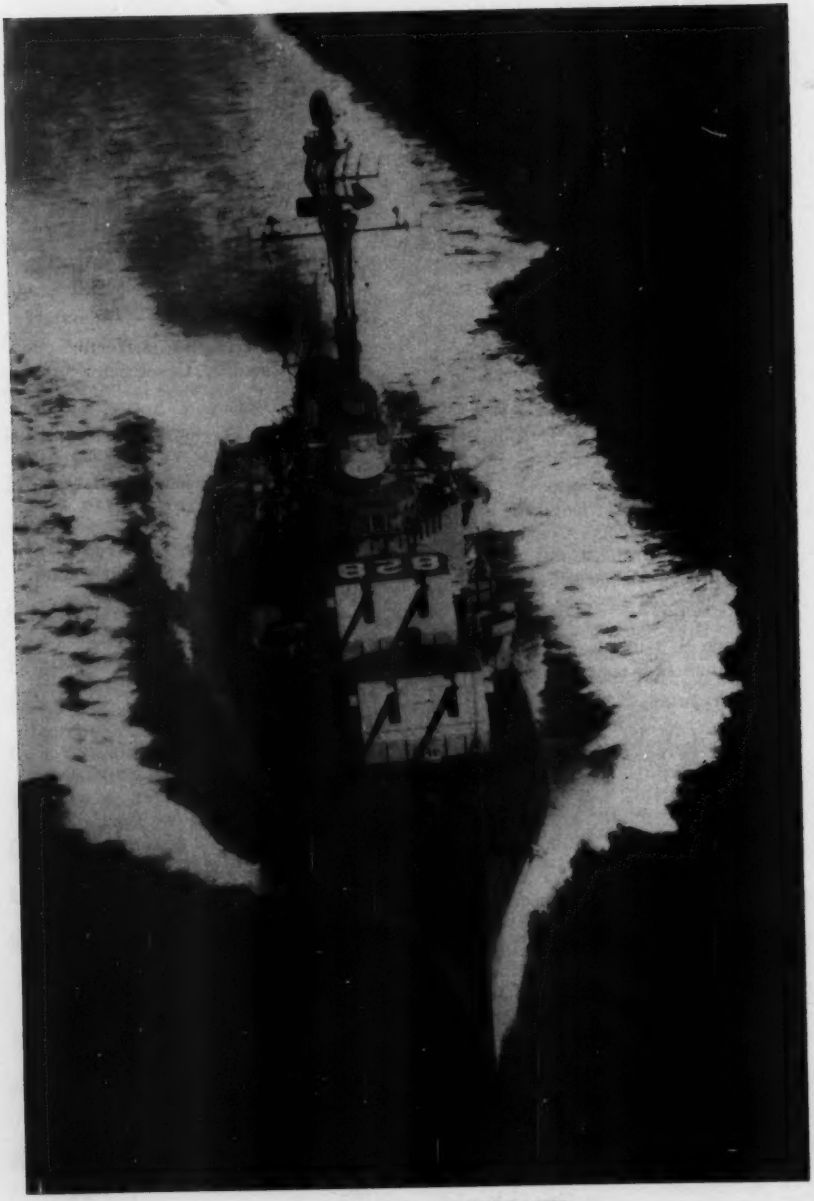
Leslie A. Kniskern, Constructor
Bernard E. Manseau, Constructor
Logan McKee, Engineer
George A. Holderness, Constructor

July 1952

Peter W. Haas, Engineer
Armand M. Morgan, Constructor

July 1953

Hyman G. Rickover, Engineer
Frederick R. Furth, Engineer (electronics)
Robert L. Swart, Engineer
Schuyler N. Pyne, Constructor
Robert E. Cronin, Engineer



U. S. S. Timmerman, (EDD 828)

THE TWENTIETH CENTURY CLERMONT

LIEUTENANT COMMANDER ROBERT J. KNOX, USN

THE AUTHOR

graduated from the U. S. Naval Academy December 19, 1941. He served as Engineer Officer of the USS *MacLeish* (DD220) and the USS *Hunt* (DD674); in the latter he also served as Executive Officer. In June 1948 he received his Master's degree in Mechanical Engineering from the U. S. Naval Postgraduate School. Since that time he has been working with the USS *Timmerman* (EDD828) machinery while on duty at the U. S. Naval Boiler and Turbine Laboratory, the Supervisor of Shipbuilding, Bath, Maine and as Engineer Officer of the USS *Timmerman* (EDD828).

The other night as I was reading to my children about Robert Fulton and the first steamboat, *Clermont,* I came to a remark about how the people said, "It will never run," and I added, "Just what they said about the *Timmerman.*" When I came to the part where Mr. Livingston, who supported the Fulton project, exclaimed, "Look at the money I've spent—if it doesn't work I'll be a disgrace," I again added, "Just what they said about the *Timmerman.*"

In the past five years I have watched the men and machinery of the USS *Timmerman* (EDD828) take shape. I have observed a true marvel of engineering. People have damned the equipment of the *Timmerman* as much as they have praised it. Most of the damning came from people who didn't know the true picture, the true background or the true objective of the *Timmerman.* For security reasons very little has been mentioned about her. For other reasons, mostly doubt as to her future, many people have shunned mentioning her.

Several basic facts have been established:

First, there has always been progress. From the very first test in a laboratory, through the building program at the Bath Iron Works, during the fitting out period in the Boston Naval Shipyard, and even in Newport when the vessel went dead in the water moored to a buoy in a northeaster (there wasn't enough power to make a pot of coffee), the vessel has always emerged showing steady progress.

Second, in 95% of the cases, when a short cut was taken to try to save time, the end result was a miscarriage of engineering principles and further de-

lay as we proceeded to take the correct, although longer, procedure.

Third, bearings and lubrication turned out to be the almost universal problem as the result of increased rotating speeds, reduced margins for loading, and increased temperatures.

Fourth, to run an experimental ship requires a highly skilled and trained crew. The date of commissioning found a hand picked engineering nucleus of officers, chief petty officers and several first and second class petty officers who had an average of 2-3 years duty with the engineering equipment. The wisdom of that move virtually meant the success of the vessel. Casualties, as the result of personnel, were cut to the almost non-existant point with a resultant maximum operation of all equipment.

Fifth, spare parts and repair parts meant continuous and costly delays. The large variety of equipment meant a large variety of spares. Close design meant many failures which depleted the stock of spares. Since each repair part was special and non-standard, deliveries ran frequently six months to one year. A plot of delays in completion dates for Naval Boiler and Turbine Laboratory tests, delivery of the vessel at Bath Iron Works and fitting out at Boston Naval Shipyard, resulted in an interesting thumb rule. Regardless of how realistic planners tried to be, the *Timmerman* progress followed a straight line function. For example, on 1 January the date for completion of a particular phase might be estimated as 1 June. By 1 June a new date would have to be set and it would be 1 September. By 1 September another new date would be required and it would be 15 October, etc., until almost the last week.

Sixth, the vendor is your best friend, a fact which many ships should learn. He knows his equipment in most cases better than any other person. He can get replacement parts, information and action from his own company faster than anyone, and if the equipment is experimental you must and almost invariably can rely upon him. His advice and assistance can make or break you, so treat him as something other than scurvy or an in-law.

Seventh, an experimental program is at first a novelty. You will find early and eager assistance from nearly everyone. As time goes by the true problems keep repeatedly raising their ugly heads and each day becomes another headache, another special procedure, another unknown, another emergency and you will find the many eager assistants looking upon you as a leper and kindly wishing you would "drop dead," to put it bluntly.

The problems of the *Timmerman* were not merely radical design and new materials, but also new thinking and doubt as to the objective on the part of many. The vessel was designed and built on the premise that if an individual piece of equipment did not fail then that piece of equipment was not designed close enough. If it did not fail then the designer still would not know where or how much excess weight or strength he had built into his machine. Manufacturers were requested to give only a guarantee of good workmanship, good intensions and their best technical brains so as to produce a product on which they would place their nameplates. In general, the results and cooperation received have been beyond one's fondest expectations. Experience to date indicates the vessel has been 99% a success because 99% of the equipment has failed in one way or another. The real success is borne out, however, by the fact that upon establishing the cause of a failure, then determining the proper remedy and finally making the modification, item by item the machinery has been made into an operating unit.

Under the old bugaboo of time and schedules, the main machinery plant

received first priority. Now that it is pretty well in line, the auxiliaries such as refrigeration, air conditioning, air compressors, emergency generators, washing machine, etc., are demanding and finally getting attention. In the early days after commissioning it was not unsual to step cautiously into the "head" and wonder whether or not this was the unpredictable hour in which the flushing system would be lacking in pressure; or to go to the wardroom for dinner only to see gold buttoned uniforms face the white linen tablecloth while flashlights in hip pockets clanked against the chairs in anticipation of a power failure.

Many wild tales have no doubt been told about the *Timmerman*. Many are true but some are so fantastic that they sound purely like tales. Others are not true but merely the subject of rumors and imagination. This condition is readily understandable when you consider the "beast" as she really is.

Unlike other previous experimental vessels, the fathers of the *Timmerman* decided to go "all out." They boosted the steam pressures, temperatures, frequency and voltage. That wasn't enough, so they made one plant over twice the pressure of the other and thereby eliminated the possibility of cross connecting the steam plants. One boiler manufacturer made the boilers for the after plant, two other manufacturers each made one boiler for the forward plant. Each of the three boilers was an individual design. The same general thinking followed throughout as they picked one vendor for one unit and a competitor for the other. If three units were involved then a third vendor was contracted. By increasing the frequency they were able to eliminate the need for reduction gears on turbine generators; the resultant increased speeds reduced motor and pump sizes by up to 75%. Higher temperatures meant new and improved insulation. Higher voltage cut down the space and weight of cable. Higher pressures cut down the space and weight of steam piping. The net result in the vessel was to cut the ratio of tons of weight per horsepower exactly by one-half from that of a standard destroyer. The present operation of the equipment indicates the general success of such a bold step.

Radical design was carried into the laundry, galley, living spaces in the form of air conditioning, vent sets the size of flashlights, steering gear, anchor windlass, electronic equipment, interior communication equipment and the gyro. In many respects the vessel already stands as a monument to engineering. Actually, this is only the beginning. Several years will no doubt be required to complete every detail. In some cases there will undoubtedly be details which will be determined to be out of consideration for any future use. The foundation has been laid and with continued slow but sure, in some cases almost plodding progress, there will emerge in the next few years a vessel which will hold engineers spellbound.

Some of the many innovations are as follows:

Steering gear—so small that the space normally provided for the main component is now a living space for six men and the entire steering gear unit is in the ram room.

Automatic combustion control—complete control of the boiler including cutting burners in and out in sequence so as to virtually give control of the fireroom to the engineroom throttleman.

Shafting—high speed, hollow, seven and one-half inches in diameter and turning in roller bearings; main strut and stern tube bearings are roller bearings with gravity oil lubrication.

Planetary reduction gear—to permit the above high speed shafting.

Forced draft blowers—no blower rooms, blowers are hung from the overhead.

Main circulating pumps—no lube oil; entirely water lubricated.

Auxiliary condenser condensate pumps—so small they look like a bellied out flange.

Turbine generators—so small both have had their rotating units removed through the main deck hatch.

Emergency generators—one gas turbine drive; one diesel "pancake" drive.

Boilers—non-controlled superheat; two boilers are forced circulation with all walls water walls except the boiler front; two are natural circulation.

Anchor windlass—hangs on the overhead out of the way.

Messing facilities—on main deck level with steam tables at galley for direct feeding of crew.

Instrumentation room — facilities for recording a thousand temperatures with fifty-point recorders and jack plug connections.

Entire aluminum superstructure—with various types of junctions in deck house, no expansion joint and a solid aluminum welded gun foundation for mount 52.

There has been a steady stream of visitors to the vessel over the past year and their amazement over the new designs have been obvious. At times one feels more like a sideshow barker than an engineer.

Good machinery, however, without good men would be a waste of time and money. The best machine in the world is worthless if a man cannot be trained to operate it. Similarly, any plant is practically worthless without properly trained personnel. This is certainly not new; yet many times it is unfortunately overlooked. Conversely, the designer must consider the man who will operate his machine.

Good men were located for "the 828" by a continuous search. When a man was recommended, he was contacted by mail or in person and requested to give references. His references were checked. If his conduct record was excellent as well as the quality of his work, he was requested for assignment to the unit. If after joining the group he didn't fit in smoothly, he was dropped; about 50% were dropped during the period at the Naval Boiler and Turbine Laboratory. The result was a hard, strong, homogeneous core of well qualified, alert, steady men.

Good conduct is as contagious as bad conduct. The result was a general rapid acceptance by new men of the standards of the "old timers."

The electrical officer, a lieutenant commander, ex-electrician, was brought in from Alaska. The boiler officer, a lieutenant, exwatertender, was in charge of the Boilerman School in Philadelphia. The main propulsion officer, a lieutenant junior grade, two years out of the Naval Academy, came from a destroyer minesweeper. The repair officer, a lieutenant, ex-reserve, came from completion of an engineering course in the Naval Postgraduate School. All were qualified chief engineers in their own right. A chief machinist mate, still with the ship, was the first enlisted man to join the unit in October 1948. The first chief boilerman to be selected, still with the ship, was an instructor in automatic combustion control at the Boilerman School in Philadelphia.

In 1950 selections for warrant officer chose five of our initial seven chief petty officers and threw our planning into a tailspin. Seven of our present chief petty officers joined the unit as first class petty officers.

At the Naval Boiler and Turbine Laboratory the men followed the erection of tests, assisted in the preparation of agenda, took data during tests and worked on the equipment when it was under repair. Seminars were conducted

in which each man lectured to the rest of the unit about a major piece of machinery. Periodic trips were made to inspect machinery and observe tests at manufacturers' plants and the Engineering Experiment Station. The unit contacted vendors, bureau and laboratory personnel. The object was always to learn every bit of information available about the machinery which these men would some day be called upon to operate and to act as instructors for their subordinates.

At Bath, Maine, a detail of four or five men were assigned daily for over a year to check, and identify spare parts. The other men continued their study, followed installation of equipment in the ship, traced out systems, read the new instruction books as they arrived, held more seminars and prepared the machinery index for the vessel. Vendors and designers came to lecture and lead discussion groups on their equipment. This concentrated and continuous training although at times reaching the point of boredom, has paid handsome dividends. Let me cite just one example. There are many like it. The credit must go to the man on the floorplates.

One night in June, about 2200, steaming along at twenty knots, a faulty regulator on the after main feed and booster pump permitted the pump to overspeed and lift the relief valve on the feed discharge line. With feed at a temperature of 250 degrees Fahrenheit, the water upon discharging to the atmospheric pressure filled the after fireroom with steam. The level in the feed water heating tank went down as if someone had pulled the plug. The boiler level began to drop. The crew were forced to "wrap up" the fireroom. With steam pressure dropping, the after turbine generator would soon lose the electrical load. The electrician on watch shifted the electrical load to the forward generator; the throttleman indicated, "Stop," on his engine order telegraph. When the power transfer took place the controller on the main condensate pump arced, kicked out, fed back through the panel and tripped the controller of the main lube oil service pump. (I know it's impossible! The impossible happens regularly on the *Timmerman*). The resultant drop in lube oil pressure set off the lube oil alarm with its siren for sound effects. The output pressure of the other lube oil pump, shaft driven, was not sufficient to provide adequate lubrication. The forward plant personnel (main engine control) noted the signal of low lube oil pressure in the after plant. They promptly signaled the bridge to stop all engines and proceeded to stop the ship in the water. With only 300 psig steam at the throttle the after engine was stopped and the shaft locked. Casualties, None. Possible casualties: one melted boiler, one burned out main feed and booster pump, all main engine bearing wiped on the after engine. Within one and one-half hour the vessel was steaming along again at twenty knots.

The sailor is a good man. He proved it during the war and he is proving it now, but he must be trained. If he can't be trained, then we must start anew to redesign our naval machinery.

U.S.S. ANTIETAM (CVA 36)

Underway during flight operations conducted to obtain a critical evaluation and analysis of the operational suitability of canted flight gear as a primary means of operating carrier aircraft.

ENGINEERING IN THE NEXT TWO THOUSAND YEARS

ACKNOWLEDGMENT

This is an abridged version of the presidential address by LORD DUDLEY GORDON to Section G (Engineering) of the British Association, delivered in Liverpool on 3 September 1953. It was published in the 18 September 1953 issue of "Engineering."

This is only the second occasion on which I have attended the annual meeting of the British Association for the Advancement of Science. The former occasion was as far back as 1897, when the annual meeting was held in Toronto, and my most vivid recollection of it is of a paper by Professor Roberts-Austen on "Molecular Movements in Metals." Certain points were demonstrated by the melting of metals in a small electric-arc furnace consisting of a crucible or porcelain bowl over which an electric arc was formed between two carbon electrodes. Lord Kelvin was present during the reading of this paper and I remember my youthful amazement when, at the end of the paper, he asked some questions of the operator of the furnace, whose name was Stansfield, as to exactly how it worked. I imagined that the great man possessed such a store of knowledge on all scientific subjects that it would be unnecessary for him to ask questions about anything from anyone.

In 1951, Sir Claude Gibb gave his presidential address on the past 2000 years of engineering. I will make an attempt to look forward instead of backward, and to suggest some thoughts of how the science and practice of engineering may develop in future years. It is perhaps appropriate to do so at the present time because, up to quite recent years, the energy from which the production of power has been derived has been mainly from heat created by the combustion of material found in the earth—wood or coal or oil. The obvious exceptions are the production of power from water falling from a high level to a lower level, which is using the force of gravity, or from wind, which is the result of atmospheric changes.

The energy made available by the combustion of coal has only been turned into useful work as the result of the construction of apparatus which, in its turn, has depended upon other minerals taken out of the earth. In the early days of the development of the industrial era, no particular care was taken to preserve such resources, because, with the rate of demand which existed at that time, they appeared to be virtually inexhaustible; but in more recent years it has been realized that, at the present rate of progress, there is a limit to these supplies. This has resulted in careful in-

as a primary means of operating carrier aircraft.

vestigations being made into the reserves which remain, notably the report by the Materials Policy Commission of the United States, appointed by the President to consider "resources for freedom," known as the Paley Report.

This report obviously deals with the matter from the point of view of the resources available in parts of the world not covered by the Communist bloc, and does not look farther forward than the next 25 years. Even over this comparatively short period, the report comments, detailed estimates are beyond the capacity of even the most electronic intelligence. This fog of the future is even more mysterious when it is realized that today, less than 10 per cent of the population of the world is consuming half the volume of the materials now being produced from the earth's surface. A striking example is the inroads made on the Precambrian ores in the Lake Superior area, where two-thirds of the known supply has already been exhausted. This is coupled with the thought that these deposits are the result of what took place as long ago as a thousand million years and that no replacement is possible. This problem of replacement does not yet apply to timber; it is suggested, for instance, that the Bowater pulp mills in Newfoundland can continue indefinitely at the present rate of output, because timber is not being felled at a rate greater than its replacement by new growth.

Minerals which are being mined today are from deposits which are reasonably accessible, but the knowledge that they are not inexhaustible has naturally led to prospecting in less accessible parts of the earth's surface. From present knowledge it would appear that these further deposits add greatly to the estimated period during which such supplies will be available for the use of man, but the cost of the necessary development and the transport of minerals to the point where they are made use of will increase considerably.

Estimates of the length of time that will be taken to exhaust the present resources of coal, which still remains the greatest source for the production of heat, vary as between different parts of the world. The Paley Report estimates, for instance, that, at the present rate of consumption, the United States coal resources are good for another 2500 years, whereas estimates for the coalfields in Great Britain are limited to something like 250 years only; some estimates, indeed, are as low as 150 years. This assumes that the increase in the rate of consumption will not ascend even more steeply than it is doing at the present time.

The most important alternative to the use of coal for the production of heat is oil, and petroleum products generally. Here the estimates of reserves available vary more greatly than those for coal, probably because new sources of oil are constantly being discovered and developed, whereas this does not apply to coal to any great extent. The Paley Report suggests that the present known sources in the free world may be exhausted within a generation. This estimate would not be affected by the addition of the resources available in Communist-controlled countries, which are unlikely to become exporters because they can do no more than meet their own requirements.

These estimates probably ignore resources which may exist beneath the bed of the oceans. These would have to be developed on the same lines as the deposits already being worked under the sea in the Gulf of Mexico, but even if these deposits do exist, new methods of exploitation would have to be devised at a greatly increased cost. The possibilities of this source of oil are discussed in Miss Rachael Carson's book, *The Sea Around Us*.

The other obvious source of fuel is natural gas, developed on the lines already in use in Canada and in Italy. It does not appear that this source will make any considerable contribution to world sources of heat over the long period under consideration. Sources such as peat and oil shale, over this period, are probably not worth considering.

So much thought is given today to the possibility of development of nuclear energy, that less anxiety exists about the question of fuel supplies than would otherwise be the case; but, at the present stage of development, materials such as uranium have to be found and are at present being sought all over the world. This is an interesting example of how material for which there is no important known use in one generation may be in great demand in another. Fifty years ago, uranium, by virtue of its close similarity to tungsten, was noted as a possible alloy to be used in tool steel, but not much progress was made. Today, we find the somewhat dramatic development of the creation of Uranium City and Port Radium in Canada—the former, I believe, largely constituted from materials moved from the former town of Goldfields.

In South Africa, the gold-mining industry is paying a great deal of attention to the recovery of uranium, which, until recent years, would have been looked upon as not worth extracting from tailings dumps, even if its presence had been realized. The strength of the South African position is that it is worth while to work the mines for the gold alone. Gold is in a quite exceptional position compared with any other metal because it is a basic medium in the exchange of currencies, and no completely satisfactory alternative has been devised. The mining of gold for its own sake is therefore likely to continue for a very long period, and uranium from this source can be obtained without the heavy overhead expenditure involved when it has to be extracted for its own value only.

It would be quite inappropriate in a presidential address making this wide survey to attempt to discuss the details of possible developments in nuclear energy. It is sufficient to say that, so far as we have gone at present, progress has been made in the direction of producing heat which is made use of to create power as an alternative to combustion of fuels, and is used in the form of normal heat engines. Maybe there will come some development by which nuclear energy could be employed directly, by the use of apparatus not yet thought of.

At present, the development of nuclear energy appears to be based on the availability of uranium and possibly thorium, which come from resources which, at the present rate of consumption, may well be exhausted before the period of 2000 years. There is, however, the thought that, by a process of reaction, there may be a type of reproduction, the so-called breeder piles, which would greatly reduce the amount of uranium required and so extend the life of the discoverable resources. It may not be outside the bounds of possibility that, in the course of development, some alternative method of producing nuclear energy might be evolved which would displace the use of uranium.

An example of the expectations which are raised by the present progress towards the development of nuclear energy is well indicated by the suggestion, made some months ago, that the coal industry would be prudent to assume that, before long, the production of power from nuclear energy will be no more costly than coal; and, for this reason, research should immediately be undertaken with a view to finding an output for surplus coal. On the other hand, it has been suggested by Sir Charles Darwin in his book, *The Next*

Million Years, that the amount of uranium at present in the earth is such that, if it is to remain the only source from which nuclear energy can be produced, it is unlikely to be as much as can and will come from coal. It is unlikely to be ten times as much and certainly will not be a thousand times as much; so that, if this assumption is correct, the supply would be exhausted well within the period of 2000 years which is under discussion.

The use of the so-called hydrogen bomb as a destructive agent has already received some attention, but just as fire, first used for cooking and warming and then as a destructive agent, was later harnessed for the production of power, so it is possible that the almost unlimited amount of hydrogen recoverable from the air or the sea might be used as a source of power. Sir Charles Darwin's book, indeed, expresses the hope that it will never be possible to release all the ordinary hydrogen in the earth because it might well involve the destruction of our planet. But there may be hopes of successful use of heavy hydrogen as a fuel.

Sources of power which do not depend on the creation of heat by combustion are obviously water power and wind. The attraction of these sources of power is that it is difficult to conceive that they could be exhausted within the next 2000 years, though there would presumably come a time much sooner than that when all the possible sources of hydraulic energy had been developed. This will surely some day include the use of energy derived from ocean tides. Here is an immense source of power which is inexhaustible. Professor J. B. S. Haldane, however, has sounded a warning that the final result of unlimited development of tidal power would be to increase the braking action of tides very considerably, so that the rotation of the earth would slow down and the day would become longer. The moon would again begin to approach the earth and the final result would be the destruction of this planet; but as he calculates that this final judgment is not likely to take place before A.D. 36 million, we need not be greatly concerned about it as a deterrent during the next 2000 years.

Experiments for the production of power from wind are already being undertaken, but in this case it would appear that the constant variations in the amount and velocity of movement of air in any given spot are so great that we cannot yet see how a large and constantly available source of power could be developed.

No attempt has yet been made to use the heat available in the inner part of this planet. There are from time to time spectacular demonstrations in the form of volcanic eruptions which give an indication of the immense resources available. These would have to be tapped by some form of excessively deep boreholes and controlled by some means not yet thought of. The danger to be avoided is obviously the release of forces which would cause some terrible catastrophe similar to the destruction of Krakatoa in 1883. There remains solar energy as a possible source of power, but again limited as to location and magnitude: a subject on which Dr. A. Parker, of the Fuel Research Station, gave a most interesting paper more than two years ago.

Generation of electricity from water power, wind, tides or solar energy can be undertaken only in those places where Nature has made such sources of energy readily and constantly available. If they are to be made of general use, they will depend on the transmission of power over great distances. Progress has already been made in this direction by the transmission of electricity in the form of direct current at high voltages, but such means of transmission must always be very costly, not only from

the point of view of the original installation, but also as a result of the high charges for maintenance. This difficulty would be overcome if some form of "wireless" power transmission could be devised. These intermittent sources of power will become more valuable when some means is found for the large-scale storage of electricity.

It seems certain that, in future years, the progress of engineering science will be more rapid than it was in the Nineteenth Century, for the reason that so much knowledge has been accumulated and that certain principles are so well established that they can no longer be doubted. I refer, for example, to the laws of thermodynamics, including acceptance of the Carnot principle, as well as to the gas laws of Boyle and Charles. The properties of steam at temperatures and pressures well beyond those in present use are well established, while in another direction we are now at home in the field of sub-zero temperatures. By parallel improvements in instrumentation also, the efficiencies of engines, machines and structures can be more closely studied, with advantage to the economy of constructional materials and of fuel.

There may be other sources of power which are as yet unexplored. I will venture to suggest that the force of gravity may some day be used as a source of power. It is used today indirectly in water-power generation of energy, but if we can learn how to control the force of gravity itself great developments would follow. If it could be controlled or even generated, and its intensity and direction varied at will, it could be used for many purposes, particularly for travel. This suggestion is obviously quite visionary. Knowledge today regarding gravitation is slight. It is true that the latest mathematical efforts have led Einstein and others to believe in a connection, rather than a mere similarity, between gravitation and magnetic force. No physical meaning to these equations has yet been found and it is possible that, as knowledge increases, it may be found that there is no hope of the control of this force by the inventions of man.

One of the most important results to mankind, in the development of the science of engineering, is the increase in the ease of movement from one part of the world to another. It was not very long after the introduction of the steam engine that it was applied to travel by means of railways and steamships. The same can be said of internal-combustion engines and, to a lesser degree, of the steam turbine, which has been applied for travel purposes so far almost exclusively to ship propulsion, though there have been examples of steam-turbine locomotives.

The increased speed and range of travel which the development of science can provide has always been a favorite subject of the novelist who makes the future his theme. Jules Verne not only imagined beforehand with considerable accuracy the development of the submarine, but also in his novel, *The Clipper of the Clouds,* describes something similar to the present-day helicopter. H. G. Wells in his novel, *The War in the Air,* was not quite so accurate in his forecast, since he visualized the dirigible airship as possessing greater striking power in war than the airplane.

Most of these forecasts assume the use of forces which were well known at the time of writing. Jules Verne, for instance, in his *Voyage to the Moon,* imagined a projectile propelled by the explosion of gunpowder in a cannon composed of a vertical bore in a mountain. In the same way today, proposals for inter-planetary travel assume the use of rocket propulsion on the basis of developments now taking place; but the control of the force of gravity, if it could be achieved, would not only make

the return journey more feasible, but would overcome the disadvantages of the varying forces of gravity during the journey and on arrival at planets which, being smaller, have a lower force of gravity than our own.

Another alternative source of power is the use of some chemical action not yet perfectly understood. Working on the principle of thermodynamics engineers attempt to design a prime mover which will use the highest possible temperature of the agent selected and collect the energy which is given off as that agent is reduced to the lowest possible temperature; but in the case of the human or other animal body which exerts power, there is no corresponding absorption of an agent at high temperature, rejected at a lower temperature. In the human body, energy appears to be accumulated in the form of food, particularly carbohydrates, without any appreciable rise in temperature; and when doing work such as turning the handle of a winch or hauling on a rope, no appreciable drop in temperature takes place. When thinking of a period as long as 2000 years, is it unreasonable to suggest that a source of power based on a more or less isothermal chemical reaction may be evolved?

So far as the immediate future is concerned, it appears to be certain that, with regard to mechanical engineering, power units will become almost exclusively those giving power by rotating rather than reciprocating motion. The first known prime mover making use of steam is generally accepted to be the classical reaction turbine of Hero, but when the steam engine began to be developed as a practical working unit in the latter part of the Eighteenth Century, the reciprocating motion was the one generally employed. Both steam and internal-combustion engines were developed on these lines, through the greater part of the power they developed was applied through flywheels and pulleys to a rotating motion, the obvious exception being the use of reciprocating pumps and compressors driven either by coupling through the crankshaft or directly by tail-rod drives.

Steam power was first used on a considerable scale for pumping water, which had for a long time been achieved by the plunger type of pump, the power being provided by men or by horses. This may have influenced the lines on which the steam engine was developed, but designers and constructors were limited by the materials then available.

The generation of electricity and the use of electrical power has always been developed through rotating generators and electric motors. It was, therefore, a natural step forward that the prime mover should also be rotating, in the form of either steam or gas turbines. The application of power by rotational movement has long been known in the case of centrifugal pumps and other similar apparatus, and in recent years there has been considerable development of turbine compressors for various uses, mainly for the larger sizes. The replacement of the immense blowing engines associated with the early days of blast furnaces, which are today superseded by rotary blowers, is an example. There is every indication that, before long, this will apply to smaller sizes as well. Gas turbines and jet propulsion for aircraft are already accepted almost as normal, and a beginning has been made with similar propulsion for motor cars and ships. It seems, therefore, quite reasonable to suppose that, certainly within the next 50 years, reciprocating motion will become the exception rather than the rule. Turbines and compressors tend to adopt constantly increasing speeds and higher temperatures, so that the weight and space occupied are constantly being reduced.

Great attention is being paid today to increasing the speed and range of air travel and it is confidently expected that

long-distance travel at supersonic speeds will become common practice within the next 20 years or so. No less an authority than Sir Frederick Handley Page has suggested that the next increase in speed, when it does come, will be in the form of a considerable jump to something like 900 miles an hour, and even higher speeds are evidently being considered. If such advances are to take place, it would seem essential that they should be accompanied by some means of reducing greatly the take-off and landing speed of aircraft, not only from the point of view of safety, but also with a view to reducing the size of airfields and the monstrously long runways which high speeds demand. This would also have the advantage of making it possible to construct airports closer to the great centers of population.

The problem of the reduction in the noise created by aircraft will surely one day be solved, as it has been so successfully in the case of motor cars. Indeed, when supersonic speed in level flight becomes the general rule, some means for elimination of noise will become a vital necessity.

Now all these advances in the science and practice of engineering are the result, first of all, of the accumulation of knowledge as the outcome of the achievements of the past; but the result of improvements in design and practice can only be made use of as a result of the materials which become available. These new or improved materials again are the result of the accumulation of knowledge being constantly added to by research, and it all goes back to the availability of the mineral resources which came into being millions of years before man was ready to make use of them and are now being so rapidly exhausted.

Whatever new sources of power may be developed, they can be made use of only by power-producing units which are made of materials that have to be extracted from the earth's surface, or produced in some other way. The power is transmitted to machines in factories which are constructed of much the same materials. The machines in the factories produce goods which again are made of the same materials, all taken from the earth's surface. Today, we think mainly of iron and steel products, though the use of other metals and plastics is becoming more and more familiar.

This leads quite naturally to the consideration of how long existing sources of supply for fuel and minerals are likely to last as demands increase, and what is to take their place when these supplies are eventually exhausted.

The use of iron and steel products, not merely for engineering apparatus, buildings and similar capital goods, but also for consumer goods, is so universal that it seems quite reasonable to measure the standard of living by the consumption of iron and steel and its final products per head of population.

APPARENT CONSUMPTION OF STEEL PER HEAD
(in Ingot-lb.)

—	Average, 1937/38.	1948.	1950.	1951.	1952.
United States	641	1131	1237	1343	1138
Canada	346	623	614	793	737
Sweden	482	625	645	715	—
Australia (a)	428	415	538	643	—
United Kingdom (b)	495	614	630	642	706
Germany (c)	596	273	469	497	654
Belgium-Luxembourg	353	757	501	488	527
Netherlands	333	326	370	428	—
France (d)	289	408	332	407	518
Italy	123	110	141	166	—

(a) Year ended June 30. *(b)* Adjusted for stock changes. *(c)* Includes Saar, 1937-38; West Germany only, 1948-52. *(d)* Includes Saar, 1948-52.

The accompanying Table compares estimates of steel consumption per head in various countries (based upon ingot production less direct exports, ignoring "indirect exports" of steel in metal goods). It illustrates the point made in the report of the Productivity Team representing the Iron and Steel Indus-

try which visited the United States in 1951: "It may be said without exaggeration that the American way of life manifiests itself in a material sense primarily in the form of goods containing steel."

The Table is a clear indication that, with improved standards of living, for which every country in the world is striving, there must be increased consumption of steel per head for as long as the available sources of raw materials make it possible to meet the demand. The Table also indicates that the increase is directly related to improved standards: that is to say, those countries in which productivity is known to be low, lag far behind those countries with high productivity.

There seems no reason to suppose that this tendency to increased consumption of steel will diminish during the next few hundred years. It is reasonable to expect that the standard of living will be gradually raised throughout the world and that, even if the present ate of increase in population does not continue as rapidly as it is now doing, the total demand will continue to increase.

There are, therefore, two problems which have to be solved—first, the provision of sufficient power to meet world demands, and, secondly, the supply of materials which will make the application of that power useful to mankind; and it is the science of engineering which will be mainly responsible for solving these problems after the possible solutions have been indicated as the result of research. There is every indication that iron and steel products will continue to be the main source of supply, certainly for the next few hundred years, and there is still great scope for development in the production of iron and steel in the direction of improved composition and structure of metals so that the same results can be achieved with a much smaller weight of material. It has been suggested, for instance, that structural steel, if more completely homogeneous, could be so greatly increased in strength that the framework of a steel building might present the appearance of a spider-web construction compared to what we are accustomed to see today.

Now of even greater importance to the future of mankind than the necessary supply of materials to provide all the equipment which, though starting as a luxury, becomes a necessity as the standard of living increases, is the provision of sufficient food, which again is in greater demand as the standard of living increases.

Sir Charles Darwin in his book, to which I have referred, has some interesting thoughts on this subject. Certainly, there has been noted the tendency for the rate of increase of population to decrease with an increased standard of living, but even so it seems not unreasonable to assume that the population of the world may double itself in a century. This leads to the interesting conclusion that in 2000 years the population would have increased a million-fold and would require a million times the amount of food at present being produced in the world. It is difficult to imagine that this could be achieved, and long before the period of 2000 years is exhausted there would be a constant struggle to provide by some means or another sufficient food to feed the population. This problem is already beginning to manifest itself, and, at all events in this country, we have become so much accustomed to rationing that it is held as a great achievement when the controls which go with rationing are removed.

Agricultural science is constantly showing how both vegetable and meat supplies of food can be increased, but these methods, in almost every case, bring engineering into play to provide the solution. One possible means of

increasing agricultural resources is the irrigation of deserts, which up till now, has been achieved by diverting water from river systems. It is possible that future developments might take the form of converting sea water into fresh water by means of condensation or some other mechanical contrivance on a scale far larger than any method now in use and, by a great development of civil engineering combined with afforestation, irrigating vast areas such as the Sahara and making them available for agriculture.

Broadly speaking, it may be said that up till now agriculture has been possible in those regions of the earth where water, evaporated from the ocean and passed in the form of clouds to the land, is precipitated in the form of rain; and one of the functions of engineering in the future may be to reproduce that action by mechanical means, so that the effect of what would be the equivalent of controlled rainfall could be applied to any section of the earth's surface.

Mention of the sea as a source from which the demands of man can be met makes one turn to some of the suggestions made by Miss Rachael Carson in her book, previously referred to. Hitherto the sources for the creation of power, and its use in the production of materials and finished goods for the use of man, have been sought almost entirely from the dry land, but it is suggested that the ocean is the earth's greatest storehouse of minerals. Apart from the estimated resources of reserves of fuels in the earth, estimates have been made of the reserves of the more important metals, in addition to iron ore. Manganese ore does not appear at the present time to have any great economic reserves, but the Paley Report suggests that improved mining methods can be expected to meet the demand for many years to come. Aluminum, as at present produced, depends on supplies of bauxite, provided that there is an ample supply of electricity at a low price, which has led to the development of hydro-electric power for this purpose. No doubt it will be necessary in later centuries to devise some other means of producing aluminum.

The Paley Report attaches the words "reserves inadequate" for many metals such as chromium, copper, zinc, lead, nickel and tungsten. These are only examples, but it must be remembered that this report refers mainly to the next 25 years, and so it seems certain that more and more attention will have to be paid to the resources available from the sea.

Two important materials are already obtained in large quantities from the sea. In the case of magnesium, it is estimated that four million tons of magnesium are normally present in each cubic mile of sea water. Magnesium is already being extracted from the sea in commercial quantities in Great Britain and may be expected, as development continues, to provide structures of greatly increased strength and reduced weight as compared with what is available today.

The other important material already being obtained from the sea is iodine. In *The Sea Around Us* it is referred to as "the most mysterious of all substances in the sea."

I have tried to indicate some of the problems which will have to be solved by engineers in the space of 2000 years. It seems reasonable to assume that we have reached a stage in the development of scientific knowledge which can form a basis for future advance with a diminishing reliance on the principle of trial and error. Thus advances will be made as the result of working out methods of which the final conclusion can be predicted with reasonable

accuracy if only materials with the necessary characteristics to make use of the new methods can be produced. It would seem, therefore, that the present generation can feel that it has not merely a great opportunity, but a great responsibility, to start now to develop methods which will make it possible for the progress of man to continue when the resources at present available have become exhausted. Failure to commence development on these lines within the next 50 or 100 years would mean that life on this planet within 2000 years might well deteriorate to a level much lower than that existing today.

THE NEW METAL TITANIUM

ACKNOWLEDGMENT

This is a condensed version of a lecture delivered by DR. MAURICE COOK before the Institute of Metals at Southport, England, on 21 September 1953. It was published in the 2 October 1953 issue of "Engineering."

During the past six or seven years or so, an enormous amount of scientific and technological work has been carried out on titanium, mostly in the U.S.A., but not only there. On work of this kind many millions of pounds have been spent, and not only is the effort still proceeding, but it is being intensified. Never before has there been in so short a time so much research activity directed to a single industrial metal.

Clearly there must be a reason and a justification for this, and indeed there is. Briefly, it is that the metal has attractive physical and mechanical properties, a high strength-to-weight ratio, and outstandingly good resistance to corrosion generally. Its importance as a very desirable if not uniquely suitable material for several aircraft components was recognized as soon as sufficient of it had been made to enable its properties to be determined, if only approximately, and for evaluation tests to be made. Much of this work was done on metal compacted from powder before techniques for melting in quantity were devised and developed.

Although its current production runs to an annual level of a few thousand tons, the use of titanium, because of its price, is limited at present for special purposes. This indeed may long continue to be the position. On the other hand, if more convenient and cheaper methods of extraction were devised, so enabling its cost to be very substantially reduced, then it might well become a large-tonnage basic metal. In these days of high metal consumption which have witnessed temporary shortages, unbalances, and high costs among some of the older strategic materials, as well as uncertainties regarding the future availability of some of them, the advent of a new metal is a matter of no little interest and moment. Especially is this so when it is known that the metal and its alloys possess properties which make them not only attractive for special uses, but suitable also for ordinary and more general applications involving large tonnage consumption.

It is, however, a far cry from the present position of expensive production and processing to what still is the purely imaginative one of manufacture at price levels even approaching those of the more costly basic metals. All the major problems connected with the extraction, melting, and fabrication of titanium, and there are indeed many, stem from its very high degree of reactivity when hot and particularly when it is molten. Its great affinity for oxygen, the extremely low free energy of its lower oxides, the solubility of oxy-

gen, and the marked embrittling effect which quite small traces of it have on the metal, have proved major obstacles in the production of titanium of satisfactory quality by direct reduction of its oxide, and in the reduction processes so far developed and worked industrially it has been found necessary to start with oxygen-free compounds. Since the molten metal attacks all the known refractory materials used for lining metal-melting furnaces and for making crucibles, because of the solubility of nitrogen and oxygen in titanium, and to a lesser extent because of its high melting point, which is at present accepted as 1,725 deg. C., special equipment and procedures involving melting *in vacuo* or in argon, far more costly to operate than the techniques usually employed for melting other metals, have had to be developed.

PROPERTIES

Titanium undergoes an allotropic transformation at 882 deg. C., above which temperature it has a body-centered cubic structure, known as the β phase, and below this temperature it has an hexagonal close-packed structure, known as the α phase. Pure titanium, such as that produced by the dissociation of titanium tetraiodide, is a relatively soft metal with high ductility.

High-purity titanium can be easily cold worked, and it can sustain deformation to the extent of reductions in area of more than 95 per cent before annealing becomes necessary for further working. Its ultimate tensile strength is, however, only of the order of 15 tons per square inch, with an elongation value, on 2 in., of between 40 and 60 per cent, and, therefore, as an engineering material or as a constructional metal in a wider and more general sense, its possibilities are not comparable with those of commercial grades of titanium or of titanium alloys.

Commercially pure titanium as produced by chemical reduction methods has considerably greater strength and lower ductility than titanium produced by the iodide-dissociation method, although the crystallographic features of the deformation mechanism are maintained. Ultimate tensile strength values of about 35 to 40 tons per square inch, with 30-25 per cent elongation, are typical of this quality of metal. The marked difference between these properties and those of the iodide metal is attributable to the presence of impurities, some of which in titanium have effects of unusual magnitude. Indeed, the technology of titanium is dominated by four impurities—oxygen, nitrogen, hydrogen and carbon—all of which form interstitial solid solutions up to the limits of their solid solubilities. They find their way into the metal at various stages of processing, and, in fact, most of the major problems arising in the production, melting, and subsequent working of the metal are associated with the necessity for excluding, or at least minimizing as far as possible, contamination by these impurities. So far as production technology is concerned, oxygen is, so to speak, in the light of present knowledge, titanium enemy number one, with nitrogen quite well behind in second place. Although their effects on processing and properties are pronounced, hydrogen and carbon are less significant impurities, since the former can be removed from the metal without recourse to remelting by heating to 800 to 1,000 deg. C. *in vacuo,* while contamination by the latter can be limited to tolerable proportions by effective control of the purity of raw materials and melting conditions.

Commercially pure titanium can be readily hot worked by forging, rolling, extrusion, and other conventional methods, but in general, it is more resistant to cold working than are most non-

ferrous alloys usually produced in wrought forms. One feature of titanium which adds seriously to the difficulty of such cold-working operations as drawing of various kinds and deep pressing, is its unfortunate tendency to seize on other metals during sliding contact with them under pressure. So far no lubricant has been found which will prevent seizure of metal-to-metal surfaces, but this can be overcome to some extent through avoiding metal-to-metal contact by oxidizing the surface of the titanium or depositing on to it layers of other substances to serve as vehicles for the lubricant. Even under these conditions, only highly viscous or semi-solid lubricants can be used with any measure of success. Thus, for example, in drawing wire or tubes the metal surface can be oxidized and then carefully coated with molybdenum disulphide or a mixture of soap and calcium stearate. Alternatively, where circumstances necessitate it, recourse can be made to the technique of sheathing with another metal, which is removed by pickling towards the end of the cold-working operations.

In addition to the need for minimizing contamination in processing and for special techniques for drawing, such as those just referred to, another factor which looms large, if indeed not largest, in the economics of current wrought-titanium production, is that scrap metal cannot be remelted and returned to the production cycle. This arises partly from the fact that massive scrap cannot be fed into arc furnaces of the type at present employed for melting titanium, and partly from the necessity of avoiding cumulative contamination which would result from repeated melting and fabrication. Considerable effort is therefore being directed toward developing furnaces capable of melting scrap in the charge and in devising processes for the removal of at least some of the contamination before remelting.

The fatigue properties of titanium are unlike those of most non-ferrous metals for the S/N curve shows an approach to a true fatigue limit. The ratio of fatigue to tensile strength is generally greater than 0.5, but the most notable feature in which titanium excels other non-ferrous and ferrous alloys in respect of fatigue-resistance is the degree to which this ratio is maintained under corrosive conditions. The impact strength of commercially pure titanium is of the order of 20 to 25 ft.-lb., and while this property is very susceptible to the presence of impurities, notably hydrogen, very much higher values characterize the pure metal.

Even at room temperature the creep properties are disappointing, and tests which have been carried out so far indicate that creep occurs when the metal is stressed near to its proof stress, which is unusual in a metal having so high a melting point. Despite the expectations there may have been in view of its high melting point, commercially pure titanium is not suitable for applications involving long-continued stresses at temperatures exceeding 350 deg. C.

Joining presents numerous problems, many of which, especially those concerned with brazing and soldering and with the welding of alloys, are not yet solved. Commercially pure titanium can, however, be readily welded by electrical resistance methods, and also by means of argon-arc techniques, provided that precautions are taken to shield from atmospheric contamination not only the molten welded metal, but also all heated parts of the base metal, including the back of the weld. In the welding operation the metal runs easily, and there is no difficulty in consistently producing sound ductile welds of good appearance.

The attractive strength: weight ratio is the feature of titanium and its alloys chiefly responsible for their demand and use in aircraft, but the other excelling characteristic of the metal is its resist-

ance to corrosion. The early optimism about this has been abundantly justified. In a series of tests in which titanium and austenitic stainless steel impellers were rotated for periods of up to 500 hours in 40 per cent boiling cupric chloride, cold *aqua regia*, boiling concentrated nitric acid, and heavily polluted sea-water containing erosive silt, it was found that while the titanium was practically unaffected after the full period, the stainless-steel specimens were all seriously corroded, some after much shorter periods of time.

This outstanding resistance to corrosion is attributed to the presence of a protective oxide film which is most stable in oxidizing environments, and under such conditions the behavior of the metal is similar to that of stainless steel, but additionally the film on titanium is resistant to penetration by the chlorine ion, and so the metal is resistant to moist chorine and aqueous solutions of many chlorine-containing compounds. Its resistance to sea-water and to marine conditions generally is of a very high order indeed. Furthermore, it is not corroded by fouling organisms in sea-water, nor is it corroded in this medium when it is coupled, for example, to stainless steel or cupro-nickel.

It is resistant to cold nitric acid up to 98 per cent concentration, sulphur compounds, strong alkalies, many organic acids, chlorinated solvents, and cold *aqua regia*. It is not affected by most foods and food products, or by body fluids, and being non-toxic it could be used for many purposes in surgery. In those solutions which do attack the metal, such as certain hot strong acids, the corrosion always appears to be general without evidence of either preferential intercrystalline or stress corrosion.

TITANIUM ALLOYS

The role which various alloying elements play is becoming more clearly defined. It is possible in this regard to classify them into several groups on the basis of relative solubility in the two phases, but in considering them more generally and broadly it has been established that most of the metallic elements so far investigated, including iron, chromium, manganese, molybdenum, vanadium, tantalum, and niobium, depress the transformation, are more soluble in the β phase than in the α phase, and tend to stabilize it. Two metals, namely, aluminum and tin, have just the opposite effect. They are more soluble in the α phase, with which they form substitutional solid solutions, tend to stabilize it, and raise the transformation. Other elements, such as oxygen, nitrogen, carbon, and boron, which form interstitial solid solutions have the same effect.

As a result of alloying, the superlatively good corrosion-resistance of the metal does not appear to be impaired, and, in general, the alloys possess the excellent fatigue and corrosion-fatigue properties that characterize the metal. Impact-strength values range from about 5 to 15 ft.-lb., according to composition, grain-size, structure, and impurity content, and although these are relatively low, they increase rapidly with temperature, values of 100 ft.-lb. being obtained with titanium-chromium-iron alloys with temperatures over 250 deg. C., while alloys have been produced experimentally with room-temperature impact strengths of over 50 ft.-lb. Although some doubt has been expressed concerning the notch sensitivity of high-strength titanium alloys, particularly when subjected to fluctuating stresses, recent evidence suggests that some at least of the duplex alloys are equal to or better than high-tensile steels in this respect.

AIR CONDITIONING AFLOAT—RECENT DEVELOPMENTS

A. S. PANELLA AND E. H. HONEGGER

THE AUTHORS

E. H. HONEGGER received his Bachelors' degree in Philosophy from Canisius College in 1932 and mechanical engineering from Buffalo Technical Institute in 1933. He was employed as engineer by a leading refrigeration and air conditioning contracting firm for ten years before coming with the Bureau of Ships. Since 1943 he has been associated with this field in the Bureau and is presently head of the Refrigeration Section. He holds membership in the American Society of Refrigerating Engineers and in the Association of Senior Engineers of the Bureau of Ships.

A. S. PANELLA was educated at the College of William and Mary and the University of Tennessee. He was employed in the air conditioning section at the Norfolk Naval Shipyard from 1940 to 1948 except for two years with the U.S.A.A.F. during World War II. Since 1948, he has worked in the Ships design division of the Bureau of Ships, and is currently in charge of the air conditioning section in that division.

In 1947, a paper, entitled "Air Conditioning Afloat," appeared in the February issue of the JOURNAL OF THE AMERICAN SOCIETY OF NAVAL ENGINEERS. It thoroughly described the history of naval air conditioning until 1946, the development of Navy standard air conditioning equipment, the physiological research behind shipboard environmental design criteria, and the experimental installations on the Navy's first two air conditioned combatant ships—the heavy cruisers, USS *Salem* and USS *Newport News*. The following article might well be considered a sequel to "Air Conditioning Afloat"—it takes up where "Air Conditioning Afloat" left off and reviews the following five years of naval shipboard air conditioning.

SALEM AND NEWPORT NEWS

The primary purposes for the *Salem* and *Newport News* installations were, first, of course, to obtain overall practical experience with air conditioned living quarters, and second, to compare operating experience with freon plants using direct expansion cooling coils against steam jet plants using chilled water cooling coils, the two combinations which in 1946 appeared to be best suited for combatant ship application.

The air conditioning machinery on *Salem* consists of three steam jet plants furnishing chilled water to cool living quarters, and four low speed (600 rpm) freon—12 compressor condenser units serving vital manned control spaces. The freon plants are fitted with freon to water heat exchangers so that all six plants permit the use of chilled water cooling coils throughout the ship. The chilled water piping system of each plant is cross-connected with that of adjacent plants to permit partial cooling in the event of refrigerating machinery breakdown or for operation at reduced load conditions. Further, the entire chilled water system is so arranged and interconnected with the hot water system that hot water can be circulated through the cooling coils in the heating season.

The refrigerating machinery on *Newport News* consists of high speed (1750 rpm) freon—12 compressor-condenser units, all supplying refrigerant to direct-expansion cooling coils. As on *Salem*, the refrigerant systems of each plant are cross-connected for standby operation. Heating is achieved by conventional duct-type steam heaters in the recirculating systems.

While the air conditioning machinery for the two cruisers differ as described above, the space design criteria, arrangement of recirculation systems, amount of replenishment air, and tonnage in each space is essentially identical.

The experimental installations on *Salem* and *Newport News* have paid off —they have firmly established current criteria and techniques for the design of combatant ship air conditioning systems and have proven that an air conditioning system designed to accommodate maximum load conditions in the tropics, can be provided for a ship without reducing its battle effectiveness.

In mid 1949, a ten-man team of air conditioning engineers from the design and technical divisions of the Bureau of Ships boarded *Salem* and *Newport News* to observe, test, and obtain first hand information. Each ship was surveyed for a two-week period while the ships were underway. Weather conditions were close to design conditions (88°F.D.B., 80°F.W.B., air; 85°F sea water), battle maneuvers were simulated, full-power trials were run. Under these conditions continuous wet and dry bulb readings were taken in approximately 75% of the air conditioned spaces, casualties were simulated on plants and the refrigerant systems were cross-connected, locations of thermostatic controls were checked, and terminal types and locations were checked. The effect of weather access and non-cooled areas on air conditioned spaces was investigated. Observations were made regarding trouble-shooting techniques. Comparisons were made of high speed reciprocating compressors versus slow speed; of direct expansion freon distribution versus chilled water application; and steam jet systems versus reciprocating compressors.

In December of 1949, another team boarded *Salem* in Guantanamo Bay and rode the ship to Boston. Weather in Guantanamo was about 85°F dry bulb, 78°F wet bulb and when the ship arrived in Boston three days later the temperature was 50°F.D.B. The aim of this team was to find out how the air

conditioning system operated during the transition from hot through mild weather.

The surveys described above probably represent the most exhaustive ventilation and air conditioning investigations made aboard a Navy ship. The investigations revealed beyond a doubt that the cruisers were so spectacularly comfortable, habitable, and clean as to be almost incomparably superior in these premises to a ventilated ship.

Experience with these installations was gratifying both as to material performance and effect on personnel; following is a more detailed discussion of various features of naval air conditioning design procedures that were proven or disproven by the *Salem—Newport News* experimental installation.

ENVIRONMENTAL DESIGN CRITERIA

As was done on *Salem* and *Newport News*, it is current practice to select equipment to maintain 78° effective temperature at approximately 85°F dry bulb, 50% relative humidity when weather air is 88°F dry bulb, 80°F wet bulb. (Effective temperature, or E.T., is an arbitary index developed by the American Society of Heating and Ventilating Engineers, which combines into a single value the effect on the human body of dry bulb temperature, humidity, and air movement.) Admittedly 78°ET is a high design condition—it is out of the commercially accepted comfort zone and borders on the threshold of sweating. However, it should be noted that naval air conditioning is intended to produce a physical environment in which men can live efficiently for long periods—an environment that will prevent sweating and thereby eliminate heat rash.

That these minimal aims have been met is indicated by the following quotes. In 1950 from the *Newport News'* medical report: "It is of some interest that heat rash was practically non-existent. This was attributed to the air conditioning system, particularly in the berthing spaces . . . ." In 1951, from the *Salem's* medical report: "In reference to the value of air conditioning of ships, and its effect on the health and efficiency of the crew, the Medical Officer compared the incidence of upper respiratory infections on the *Salem*, against those published of the ships of the Atlantic Fleet, operating under the same conditions, and found that upper respiratory infections have been held to an almost unbelievable minimum; and lower than those reported by all Naval Hospitals. It is the Medical Officer's opinion that the air conditioning of ships has proven very efficient in the prevention of such infections and should be made standard throughout the Navy."

"With regard to the air conditioning, sleeping under blankets contributes to a good night's rest and thereby indirectly helps to prevent respiratory infections. In addition, clean bedding does not become soaked with perspiration, and living compartment odors are reduced to a minimum."

It has not been demonstrated to the naval air conditioning engineer that he should go to a lower ET. At maximum load conditions, which exist a very small percentage of the life of a ship, the present requirement produces an acceptable environment with a minimum of equipment, weight and space—always prime considerations to a naval architect. Data from the Guantanamo surveys revealed that, under average weather conditions of 84°F, dry bulb, 78°F wet bulb, the "78°ET" system maintains approximately 75°ET in the ships.

EFFECT OF MACHINERY SPACE AND WEATHER ACCESSES

The *Salem* and *Newport News* surveys revealed that above all other considerations, extreme care must be exercised in the arrangement, location, and design of machinery space accesses and weather doors.

On ventilated ships it is the practice to provide 20% excess mechanical exhaust over mechanical supply in machinery spaces. Approximately half of the excess takes into account the expansion of air from about 90°F dry bulb (supply air temperatures to the space) to the leaving air temperature of about 140°F dry bulb; the other 10% insures an indraft to the hot machinery space thereby precluding the possibility of "hot" air backing into the ship through the machinery space accesses which are normally open and located in passageways or living quarters.

The cruiser machinery spaces were provided with 20% excess exhaust. To minimize the gross loss of cooled air, one access, located in an air conditioned passageway was trunked in and fitted with a spring-loaded, metal joiner door; a natural supply duct was led from the trunk to the weather to cool down the access trunk and to help alleviate the pressure differentials set up in the machinery space.

It was found that this trunking arrangement did not adequately prevent excessive indraft—and consequent loss of conditioned air—to the machinery space. The physical effort required by personnel to open or close the door against the pressures set up by the machinery space ventilation was a real inconvenience but even more important, it was conclusively proven that standard joiner doors could not take the beating in this highly trafficked access. In short, the doors were not tight.

The design of the cruiser installations was further based on the assumption that weather accesses—all of which were provided with self-closing devices—would be kept closed. In keeping with this assumption, intakes to recirculation systems were located in passages, and the passages were used as return air plenums. It was found that the self-closing device:

(a) Aggravated the already existing maintenance problem of keeping the weather doors watertight and,

(b) Excessively increased the effort already required to open a cumbersome watertight door.

The result was that the ship removed the self-closers and secured the doors in the open position. Obviously, with weather accesses open to passageways that were in common with machinery space accesses, and with air conditioning systems taking air from these same passageways, the effect of the air conditioning system was in many cases completely nullified.

To correct these deficiencies on the cruisers the following action was taken:

(a) Light-weight bulkheads, fitted with metal joiner doors and self-closing devices, are installed in passageways in some convenient location between air conditioned country and the weather. The metal joiner doors are relatively easy to open, and every effort is made to locate them away from main fore and aft or athwartship passages in order to reduce traffic through them.

(b) Where air conditioned spaces are of necessity located adjacent to "weather" passages, the return air ductwork of the recirculation system is led back directly to the spaces served by the system.

(c) Where accesses must be located in air conditioned country the accesses are trunked; provided with a natural supply trunk from the

weather, and the trunk is fitted with an easy-to-operate, special balanced door. These balanced doors are hinged or pivoted at a point about one-third of the way in from the edge of the door so that the machinery space pressure differentials assist personnel in opening or closing the door. Pilot models of the door were tried on *Salem* and proved so successful that they were installed on all subsequent air conditioned designs.

In addition, on subsequent designs:

(d) Machinery space exhaust air quantities were reduced from 120% to 110% of supply to reduce the indraft of conditioned air to the machinery spaces. However, the new balanced doors described above have proven so effective that the exhaust differential has recently been increased to 15% of supply.

(e) Where possible, machinery space accesses were located in unconditioned areas.

Figures 1 and 2 more clearly illustrate access treatment "before" and "after" the cruiser experiences.

SIMULATED CASUALTY

The refrigerant distribution systems on both ships were not provided with stand-by equipment for emergency use in the event of a casualty but were cross-connected to:

(a) Permit shut-down of certain compressors and more efficient operation of the remaining compressors during light-load conditions, and

(b) To provide a measure of standby cooling in the event of compressor casualty. In the infancy of extensive air conditioning it was the honest opinion of many people that a standby ventilation system should also be installed on air conditioned ships.

Simulated casualties on *Salem* proved that the provision of duplicate ventilation systems or standby compressors was unnecessary. For example, the machinery for plant #1 one secured and the chilled water systems of plants #1 and #2 were cross-connected. In the three-hour "casualty" period, under conditions close to maximum load, the average rise in effective temperature in the spaces served by the two plants was approximately 3 degrees: occupants of the spaces were completely unaware of the situation. This rise is acceptable—similar conditions could not have been maintained with a ventilation system.

DIRECT EXPANSION FREON DISTRIBUTION VERSUS CHILLED WATER APPLICATION

The considerable differences of opinion that existed at one time as to the relative merits of direct expansion freon systems as compared to chilled water circulating systems was definitely resolved by *Salem-Newport News* experience. This experience clearly indicated that the operational advantages of chilled water far outweighed its weight disadvantage.

The chilled water system, though using more equipment, offers a system which isolates the freon cycle, making it far simpler to install, observe and maintain than a multiple coil direct expansion system. The difference in maintenance requirements was an outstanding comparison.

The actual and potential leakage of the direct expansion system was exces-

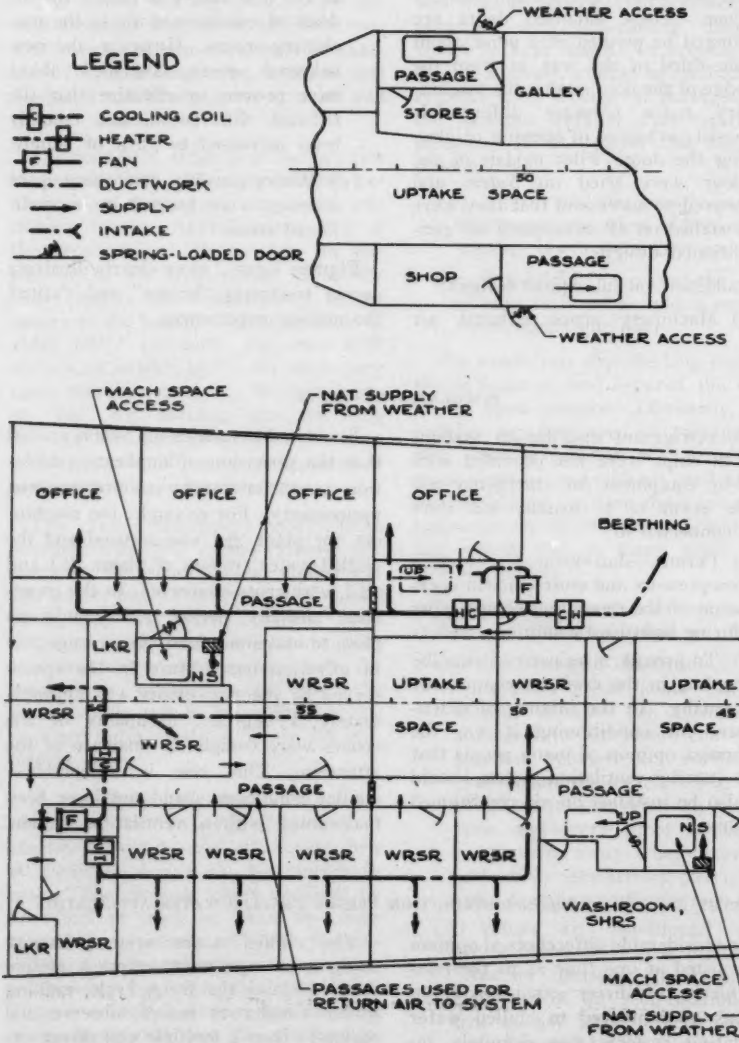


FIGURE 1: TYPICAL ACCESS TREATMENT BEFORE CRUISER EXPERIENCE

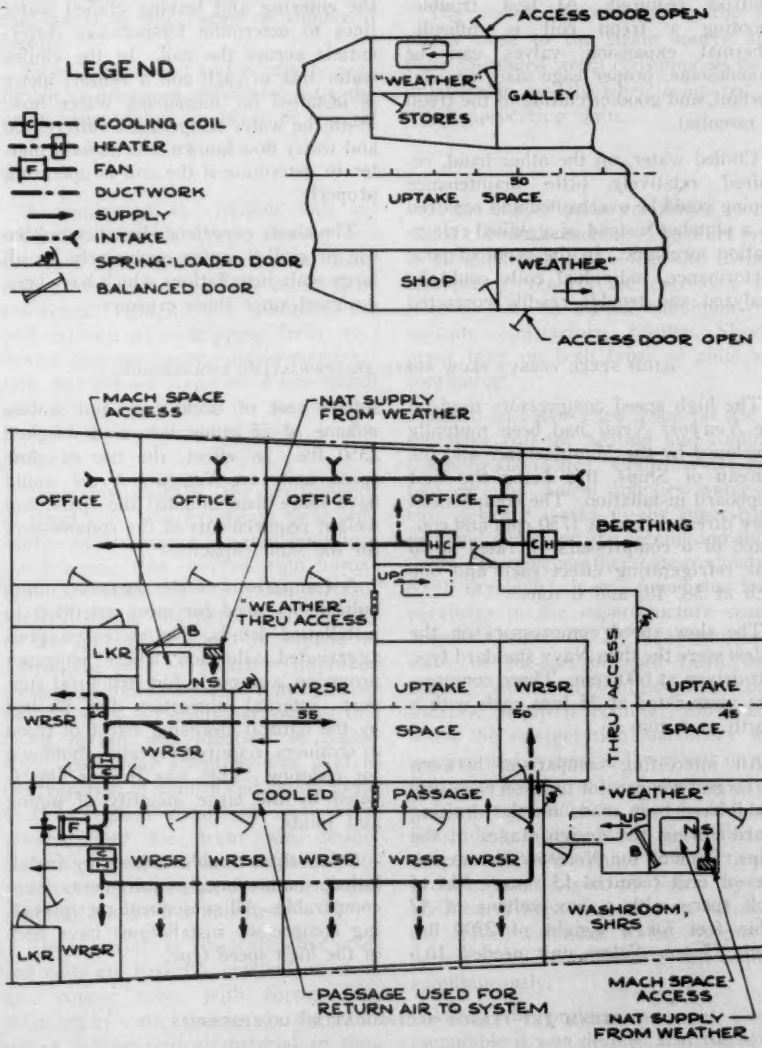


FIGURE 2: CURRENT TYPICAL ACCESS TREATMENT

sive. The maintenance problem was further increased by the multiplicity of controls required. At best, trouble-shooting a freon coil is difficult. Thermal expansion valves can be troublesome, proper cage sizes are important, and good circuiting of the freon is essential.

Chilled water, on the other hand, required relatively little maintenance Piping could be overhauled and repaired by a plumber instead of a skilled refrigeration mechanic. In the event of poor performance, individual coils could be analyzed and trouble readily corrected by shipboard personnel. Each cooling coil is fitted with thermometer wells in the entering and leaving chilled water lines to determine temperature differentials across the coil. In the chilled water line to each coil a venturi meter is installed for measuring water flow. With the water temperature differential and water flow known it is an easy matter to determine if the coil is operating properly.

The above experience has dictated the use of chilled water exclusively on all large scale installations which have been designed since these cruisers.

HIGH SPEED VERSUS SLOW SPEED RECIPROCATING COMPRESSORS

The high speed compressors used on the *Newport News* had been mutually developed by the Manufacturer and the Bureau of Ships, this being the first shipboard installation. The compressors were direct-driven at 1750 rpm and consisted of 6 compressors—3 rated at 50 tons refrigerating effect each and one each at 38, 19, and 6 tons.

The slow speed compressors on the *Salem* were the then Navy standard type belt driven at 600 rpm. Three compressors were rated at 25 tons each with a fourth at 6 tons.

An interesting comparison between the largest compressor units on each ship could have been made on the drafting board during the design stages of the ships. Each 50 ton *Newport News* compressor unit required 13 square feet of deck space with a box volume of 42 cubic feet for a weight of 2200 lbs. Each 25 ton *Salem* unit needed 16.6 square feet of deck area and a box volume of 75 cubic feet, and weighed 2350 lbs. In effect, the use of slow speed units on *Newport News* would have more than doubled the space and weight requirements of the compressors for the same capacity.

A comparison of the operating units indicated a need for more attention to installation details. The increased speed aggravated vibration where improper provision was made for structural support. Internal fabrication dirt, washed by the natural cleansing effect of freon to strainers, required repeated shutdown for cleaning. This was further aggravated by the large quantity of piping and joints.

Other than troubles caused by installation, maintenance requirements were comparable. All subsequent recriprocating compressor installations have been of the high speed type.

STEAM JET VERSUS RECIPROCATING COMPRESSORS

The steam jet plants used on the *Salem* were purchased from three different manufacturers, each furnishing one unit having capacity of approximately 65 tons. (Approximately 15 tons being allocated to line loss.) Comparative evaluations of the units were made on the testing floor at the Engineering Experiment Station, Annapolis, before the units were installed aboard ship.

Certain design deficiencies were corrected, and the characteristics of the accepted plants were confirmed through the operating experience of shipboard service.

Ease of operation and relatively negligible maintenance difficulties were the outstanding points in favor of the jet plant, as compared with the reciprocating compressors.

The desirability of locating the jet plants close to the steam source and their calculated steam consumption were unfavorable aspects when compared to the reciprocating units.

COILS

A number of the cooling coils installed on *Newport News* showed evidence of poor freon distribution, many coils performed at as little as 75% of theoretical capacity. In addition, the coil casings were dripping from condensed ambient vapor. *Salem* construction was behind *Newport News* which afforded an opportunity for the installation of a new series of coils, in the *Salem*.

Thermodynamically, the performance of these coils was excellent; their only source of annoyance or complaint was the dripping that resulted from formation of condensation on some parts of the coil casing and particularly in way of the coil drain pan. Subsequent to *Salem*, the coils were further improved to correct the deficiencies noted during the surveys. Performance-wise, this latest design was identical to *Salem* coils; particular attention was paid to the reduction of uninsulated casing metal and foam-glass insulation was incorporated into the drain pan design. Laboratory reports and shipboard installations indicate that the condensation problem has been eliminated.

The materials in Navy standard cooling coils are basically copper and steel, i.e., copper tubes with copper fins, mounted in a steel casing. In the interest of saving critical material in time of war, and to reduce weight, the Navy is experimenting with two new types of coils. One has copper tubes with aluminum fins mounted in an aluminum casing; the copper tubes are tinned to reduced chemical reaction. The other type is all aluminum tubes, fins and casing. Laboratory reports on corrosion resistence tests on the all aluminum coil indicate satisfactory results. Shockproof tests on both types of coils are continuing.

Based on *Salem* experience, the use of the same coil for heating and cooling, has been abondoned. Chilled water system #1 on *Salem* supplies water to coils serving spaces in the superstructure and spaces on the second and third decks. In mild weather (approximately 55°F dry bulb), it was found that temperatures in the superstructure spaces dropped below 65°F; simultaneously, some of the second and third deck spaces, which are adjacent to heat sources, required cooling. Obviously, when the refrigeration machinery was secured and system #1 was put on the heating cycle to satisfy superstructure heating requirements, the second and third deck spaces were unsatisfactory due to lack of cooling. This particular problem was solved on *Salem* by the addition of bypasses and stop valves in the chilled-water-hot water systems to permit independent heating and cooling simultaneously.

While the problem was not insurmountable it was decided that the small additional cost of separate heating coils more than offset the operational problems associated with a "single coil" system.

CONTROLS

With the general exception of submarines, where control of humidity is essential—particularly when operating in cold climates, naval shipboard systems are provided with dry bulb control of space ambient. A thermostat opens or closes its electric contact-maker which in turn opens or closes a low voltage solenoid valve installed in the refrigerant line from the cooling coil. By careful calculation and selection of coils and by rigid control of air quantities, the dry bulb control system automatically dehumidifies down to an acceptable level. The system is simple, rugged, reliable, and virtually tamper proof.

At the time of the *Newport News* and *Salem* designs, it was general practice to provide a separate cooling coil and frequently a separate fan in each electronic space. This practice resulted in the following problems:

(a) Installations were noisy and consequently unacceptable, particularly in CIC's and Sonar Control rooms.

(b) Room for the relatively large fans and coils in already crowded areas resulted in unsatisfactory arrangements.

Based on this experience, a slightly more sophisticated control system—still utilizing "dry bulb" control only—has recently been used for air conditioning systems serving vital, manned, electronic spaces. By giving careful consideration to arrangements in the early stages of the design, fan and coil rooms are being provided adjacent to a group

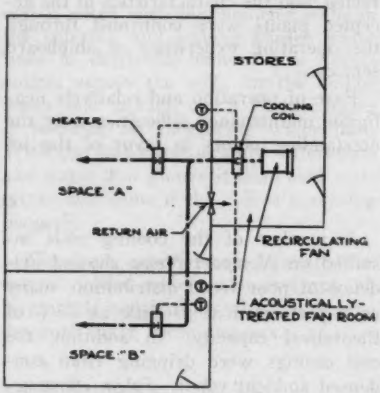


FIGURE 3: SYSTEM ARRANGEMENT FOR ELECTRONIC SPACES

of electronic spaces. One fan and one cooling coil is installed in the fan room to serve the entire group. A thermostat for coil control is provided for each space in the group with the thermostats wired in parallel so that any one thermostat may open the cooling coil solenoid. In addition, a duct type heater is installed in the supply branch to each space, controlled by a room type thermostat. With this arrangement, consider a single cooling coil serving spaces "A" and "B." If space "A" requires cooling its cooling coil thermostat will open the refrigerant solenoid. If at this time space "B" is in a light heat load condition, its heater thermostat will open the steam valve to prevent excessive cooling.

Figure 3 more clearly shows the system described.

USS NORTHAMPTON (ECLC-1)

While the experiences with *Salem* and *Newport News* had pointed the way to improved application of air conditioning "low side" problems there remained certain problems with respect to the refrigerating machinery or "high side."

The ideal machine that requires no space, weight or moving parts and still has excellent efficiency characteristics has not been found. Compromises have dictated the type of equipment developed and used. "High side" equipment has

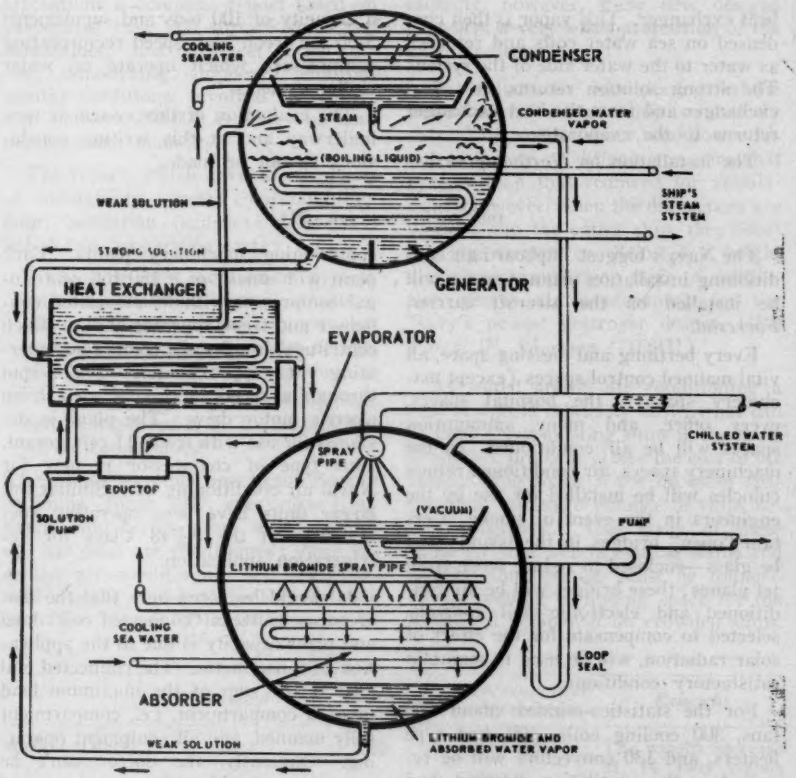


FIGURE 4 - LITHIUM BROMIDE CYCLE

been satisfactory but looking to the future this same equipment may not be suitable. Specifically, in the case of submarines, structure-borne vibration must be minimized.

In the search for such equipment, an absorption system as used for commercial air conditioning appeared to be the answer due to its lack of moving parts. A marine type lithium bromide plant was developed, tested and installed on *Northampton* as an experimental installation.

The lithium bromide cycle, shown schematically in Figure 4, uses water as the refrigerant and lithium bromide solution as the absorbent. The water to be chilled is sprayed into the evaporator chamber which is maintained at a low absolute pressure approximating the vapor pressure corresponding to the desired chilled water temperature. A portion of the sprayed water flashes, cooling the remainder which drains to the chilled water pump for circulation through the cooling coils. The flashed vapor is absorbed by the sprayed lithium bromide solution which in turn is partially delivered to the generator where the vapor is boiled off by a steam

heat exchanger. This vapor is then condensed on sea water coils and returned as water to the water side of the system. The strong solution returns to a heat exchanger and from the heat exchanger returns to the evaporator.

The installation on *Northampton* has a capacity of 100 tons and supplements 5-50 ton freon high speed reciprocating compressors which operate on water chiller systems.

The evaluation of this system is now underway and at this writing conclusions cannot be made.

USS FORRESTAL (CVA59)

The Navy's biggest shipboard air conditioning installation planned so far will be installed on the aircraft carrier, *Forrestal.*

Every berthing and messing space, all vital manned control spaces (except machinery spaces), the hospital spaces, every office, and many ammunition spaces will be air conditioned. In the machinery spaces, air conditioned refuge cubicles will be installed for use by the engineers in the event of smoke. Certain "open" bridges in the island must be glass—enclosed to reduce noise from jet planes; these bridges will be air conditioned and electronic coil controls, selected to compensate for the effect of solar radiation, will be used to maintain satisfactory conditions.

For the statistics-minded, about 400 fans, 300 cooling coils, 400 duct type heaters, and 130 convectors will be required in the ventilation, heating, and air conditioning systems on *Forrestal.* When contract plans and calculations were completed the connected coil tonnage was in excess of 1100 tons.

The coils, using chilled water as a refrigerant, will be served from seven air conditioning machinery plants. Each plant will consist of a 150 ton centrifugal compressor with its associated condenser and freon to water chiller. Each centrifugal is a 2-stage compressor operating at approximately 7000 rpm through a speed increasing gear from electric motor drive. The plant is designed for use with freon-11 refrigerant. This type of compressor is new for Naval air conditioning use. Similar but larger units have been operating successfully on the AF48 Class for refrigeration application.

It should be noted here that the discrepancy between "connected coil" load and plant capacity is due to the application of a use factor. The connected coil load is the sum of the maximum load in each compartment, i.e., compartment fully manned, and all equipment operating. Obviously, the doctor can't be operating, in his office, eating, and sleeping simultaneously. Nor can sun load simultaneously develop on both sides and the horizontally exposed surfaces. Consequently, a use factor can be applied to connected coil load when selecting "high side" machinery.

AIR CONDITIONING AND HABITABILITY

In 1951, the Chief of Naval Operations stated that habitability is "as much a military characteristic of a vessel as its armament, or any other major feature which justifies the purpose for which the ship was constructed" and directed the Commander of the Navy's Operational Development Force to "conduct a survey aboard all types of Naval vessels based on war complement, of the facilities affecting health, comfort, sanitation and morale, and review standards for living, berthing, messing and sanitation, and other factors affecting habitability."

The Commander, Operational Development Force has completed the survey and submitted to the Chief of Naval

Operations a complete report based on surveys of over 200 surface ships and submarines. Just one facet of the survey, establishing shipboard environmental conditions, involved the collection of over 750,000 readings of temperature and humidity.

The report, which covered all phases of habitability—space, color, lighting, odor, sanitation facilities, etc.—established two outstanding facts:

(a) The best ventilation system, on a ship operating in tropical waters, cannot maintain an environment that will meet even the *minimum* acceptable physiological requirements.

(b) The only way these conditions can be improved is by the installation of air conditioning.

These facts were not new to the Bureau of Ships. Since 1947, every new combatant ship design, from destroyer size up, has been air conditioned; more recently, air conditioning was incorporated into the design of the Navy's latest destroyer escorts, DE1021 class. Admittedly, however, these new designs represent a very small proportion of the existing fleets.

To include air conditioning in the basic design for a new ship is relatively easy. The weight, space, and power required for air conditioning is somewhat greater than that required for ventilation. However, when the differences are worked into the entire ship, they literally lose themselves. Below is a weight and power comparison table of ventilation versus air conditioning for the Navy's newest destroyer design, USS *Forest W. Sherman* (DD931).

As stated above, air conditioning a new design is relatively easy; what can be done about existing ships in the fleets is another problem. Here the cost of air conditioning soars, if for no other reason than the large number of ships being considered. Also many of these ships are in a weight critical status and weight compensation must be found—to say nothing of finding space for the additional equipment on crowded ships.

	Ventilated	*Air conditioned*	*Increase over Ventilation*	*Remarks*
Weight (tons)	36	50	49%	The weight increase of 14 tons equals 0.4% of ship's displacement
Power (KW)	205	245	20%	The power increase is 2.0% of total generator capacity

CONCLUSION

There is no longer any necessity for proving the need of air conditioning. Nor does this paper attempt to indicate that there isn't much to learn about the art of installing it. The immediate problem is to find ways and means of air conditioning existing ships. The big problem in the future is to find ways of reducing cost of installation, maintenance difficulties and the weight and size of equipment and at the same time further improve comfort.

THE FIRST HUNDRED YEARS OF RESEARCH AT THE FRANKLIN INSTITUTE

ACKNOWLEDGMENT

This article was written by MR. THOMAS COULSON, Director of Museum Research of The Franklin Institute. Published in the July 1953 issue of the "Journal of The Franklin Institute" it is of particular interest to members of The American Society of Naval Engineers because the early work of The Franklin Institute was so closely allied to Naval engineering

Knowledge gained from experience is probably the most trustworthy. This reflection, and no capricious decision, caused Federal authorities to turn to The Franklin Institute in 1942 when it became apparent that the normal processes of research were inadequate to meet the national needs for conducting a modern war against a bold and unscrupulous aggressor. It was natural to turn to the Institute at a time of crisis for, more than a century earlier, the resources of its members had been enlisted to conduct the first technical research for which Federal funds had been appropriated. For more than a century after the initial step had been taken the members of the Institute continued their work in the interests of public welfare, with no other recompense than the reward which comes from the accomplishment of a necessary task satisfactorily concluded. The record of achievement is a memorable one and has the merit of deserving a much wider recognition than it has achieved.

Today, when men may look confidently to the magnificent laboratories of the government departments, of educational institutions, and of industry for the discoveries which, through their applications, will enrich our lives, it is no easy matter to picture that stage of civilization when the most important discoveries issued from humble attics, cellars, and barns, where individuals devoted their lives in isolation to the accomplishment of self-allotted tasks.

The research methods adopted by the members of the Institute changed the picture by establishing the tradition of co-operative research, or research by a team of workers who provided a variety of skills developed in more than one field.

The nation had not completed fifty years of independent existence when the Institute was founded. The experiment with freedom from external control and the inter-relationship of men within the nation had absorbed so much energy that the few students of science were

compelled to follow the leadership of Europeans. The value of science to the manufacturer for the production of new industries and the improvement of the processes in established industry is a familiar theme today, but we must make a mental effort to visualize a social condition in which the idea was a complete novelty existing in the minds of a few enlightened men. Only an elementary effort had been made to emancipate Education from mediaeval conditions. Scientists were still known as philosophers and were rarely to be found outside their laboratories. This remoteness from practical affairs had caused science to fall far behind invention, which had fallen into the hands of empiricists who had no aptitude for the mathematical formulas that are conventional in our day.

The time of the Institute's foundation was witnessing a change in this order. A series of inventions (notably that of the steam engine) was bringing about the Industrial Revolution that was to change the entire social context. Industry was feeling its birth pangs. In America it could not be detected by any prophetic thunderous roll of approach, not even by a distant rumble. Only by listening intently could an eager ear detect an occasional chirrup of hope, and the vision of aggregation and integration was as audacious as trying to make a suit of clothes from nothing but buttons and button-holes.

These factors must be realized before anyone can understand the significance of the Institute's role in research. The word "research" was hardly in the vocabulary of the American, when the members of the Institute undertook their bold experiments. The Republic was in its infancy. Its people abhorred pageantry and hugged to its collective breast a narrow dull level of life. It was busy, frantically busy with ax, saw and hammer; so fully occupied with its physical problems as to have little leisure for imagination. The mental atmosphere was unfavorable to major changes. "Everything may be made better" may have become an American assumption after years of experience in improving things, but no such attitude of mind prevailed in the first quarter of the nineteenth century. Fluid capital was scarce and what there was of it was invested in land, so that a manufacturer who contemplated introducing an innovation had to proceed cautiously. The normal practice was to set up a workshop and see if the idea worked. If it did, the manufacturer had to face the discouragingly slow process of selling and distributing in a country which had few good roads and newspapers to aid him in reaching consumers.

When The Franklin Institute was founded, its members did not contemplate the establishment of a research laboratory in the modern conception of the term, they were content with the more modest hope of developing an "experimental workshop," with the intention of assisting national manufacturers and of encouraging them to make the nation independent of the products of British factories. The Committee on Inventions (the name was changed to the Committee on Science and the Arts, which it still bears) was active in assisting the individual inventor, but the need was recognized for a broader framework which would embrace fundamentals of more general aspects. The idea took root almost through accident.

DRY DOCKS

A design for a dry dock had been submitted for the Institute's approval when it occurred to some members that the whole subject was so little known in this country that it should be considered in its broadest aspects. "The large ships of war of the nation are at present suffered to decay when serious

repairs are requisite, which might easily be performed if dry docks were in existence in the Union. The danger and expense from this neglect require immediate attention, and the national welfare demands the establishment of docks without further delay." The common practice of "heaving down" a ship in need of repairs to the hull was condemned as dangerous, expensive, and incomplete. American shipowners who found their larger vessels in need of such repairs were in the habit of seeking a charter for a voyage to Europe where the vessel could be dry docked. The case as submitted to the Institute justified a thorough investigation by a group of experienced naval constructors so that the report they presented might serve as a foundation upon which either public or private enterprise could build.

A special committee was accordingly appointed to undertake this work in 1826. Their illustrated report, published in the following year,[1] reveals with what enthusiasm the members performed their task. They described the methods adopted in Europe for the construction and operation of dry docks, capital and maintenance costs, and generally described the means by which the shipbuilding industry might provide a remedy for a major deficiency in its facilities. A special feature of this report which shows the progressive spirit animating the Institute members is contained in a paragraph in which the employment of a steam-operated pump was considered. This, it should be observed, was at a time when there were a bare score of steam engines operating in the country.

Nothing of a similar nature had been attempted in this country. The pioneer effort at applying team-work to the investigation of industrial problems was an accomplishment which reflects the highest credit upon the public spirit displayed by the original members, who thereby set an example which was to be followed in later generations.

WATER WHEELS

It was the era of water power as a prime mover for factory operation. Moreover, it was the time when metal was replacing wood and machinery was rapidly being introduced. Rotary motion had been applied to the steam engine but, while steam was becoming widely adapted to both land and water transportation, it did not appear to offer any serious challenge to water power, which was so freely abundant that almost every village had its mill. Yet, in spite of its antiquity and its widespread adoption, the water wheel had been sadly neglected by the men who built and operated it. The theories, such as they were, upon its power were frequently contradictory. A few experiments had been made by Bossut in France [2] and more extensive investigations by Smeaton in England [3] but these studies were ripe for revision with sixty years' experience to draw upon. The work of individuals was to be supplemented by the combined labors of a group of men with broad qualifications. A special committee was appointed to "make experiments of sufficient magnitude to fix the data from which calculations could be made with accuracy" upon wheels of various types. The committee organized its operations to make the most comprehensive study the available funds would permit.

The question of funds enables us to introduce the comment that the members of all the Institute's special investigation committees accepted their tasks without any recompense or reward. The Institute rarely had the money or the materials necessary. Where the committee members or the Institute could not pay the expenses,

it was necessary to raise funds among the members at large or from favorably disposed outsiders. In this case of the water-wheel study an appeal for funds resulted in the collection of $2000 and permission from the city to use the water works and dams for experiments. At a later date permission was granted to use one of the city water mains. A plot of ground at Vine and Ninth Streets was offered by Messrs. Rush and Muhlenberg [4] on which a temporary building was erected in which experiments could be made, and four experienced millwrights were engaged to construct models. It is worth recording that these voluntary workers took their responsibilities so seriously that they introduced a fine of 12½ cents to be inflicted upon those of their number who arrived late at meetings and one of 25 cents for failure to attend.

The millwrights constructed a water wheel with a diameter of 20 feet at a cost of $1300. No sooner had the wheel been completed than it demonstrated the capricious nature of this form of power. Winter set in, and the frosts caused a postponement of the investigations until the spring of 1830.

When work was resumed it proceeded at a rapid pace. Over 700 experiments were conducted with breast, overshot, and undershot wheels. Special devices were contrived for measuring the amount of friction on the shaft under different loads and the amount of power furnished by wheels of various diameters. Different types of buckets were tried under varying heads of water. It was intended that nothing should be left to chance in determining the best construction of a wheel in relation to the available flow of water. The information provided on the overshot and undershot types was of special value, since most of those adopted in this country were of the breast type.

The results of the experiments were ably digested and published over a period of years in the Journal, with many tables giving details of the intensive tests.

STEAM BOILERS

While the work of this committee was proceeding, attention was drawn to a phase of power which was to supplant water. Professor W. N. Keating, one of the founders of the Institute, mentioned that "Numerous accidents had occurred on steam boats, the effect of which is to impair the confidence of the public in the merit of an invention which has shed vast honor upon the American name and which has essentially contributed to the prosperity of the country." He proposed setting up another special committee to investigate the causes of these disasters and to make recommendations to reduce the frequency of their recurrence. It was most appropriate that such work should be undertaken in the city which had been the site of the first successful steamboat trials and the original application of high pressure steam in boilers. A special committee was promptly appointed.

This committee was fortunate in securing as its chairman the energetic Alexander Dallas Bache, who was at the time Professor of Natural Philosophy and Chemistry at the University of Pennsylvania. Largely through his guidance the committee adopted a scientific method for their investigation. The first step was to issue a circular letter inviting correspondence from all those who had had any experience of a boiler explosion and had collected evidence upon its apparent cause. The replies were published in the Journal and later republished in pamphlet form.[5] The number of responses to the letter was disappointing and the opinions expressed

in the replies were inconclusive, but the distribution of the pamphlet provoked a flood of replies of much higher value. With the testimony these provided, the members of the committee set about correlating the evidence. At once it became evident that the absence of any reliable criteria led to a wide conflict of opinion upon the strength of the materials employed in boiler construction and the methods of joining the plates.

The cylindrical iron boiler was in general use, having replaced the old oak-timbered boiler with its metal braces. But the greatest confusion reigned upon the properties of the metal employed. There was a lack of knowledge that imprisoned steam possesses some of the qualities of a high explosive, and the prevailing ignorance permitted the employment of inexperienced men to operate the boilers. Investigation had revealed that boilermakers had no accepted standards; safety factors were either unknown or not observed.

Since no one had clear views upon the pressures which were required nor which could be held in restraint by the materials of construction, the committee determined to arrive at some criteria which would be of service for the future. The members divided into two groups, one of which was to concentrate upon investigating the properties of steam with special apparatus designed for the purpose, the other was to wrestle with the problem of the strength of the metals (iron and copper) used for boiler construction. The members of the Institute were asked to cooperate in the raising of funds to defray the cost of building the necessary apparatus and conducting the experiments. Meanwhile, government authorities had become gravely concerned over the increasing loss of life and damage to property through explosions and had drawn attention of Congress to the dangerous situation which was retarding the more general adoption of steam power while European countries were freely adopting it. Congress voted a sum of money which was to be applied to gathering information.

When news of The Franklin Institute committee's work reached him, the Secretary of the Treasury (S. D. Ingham) wrote to inquire about the nature and scope of the research they were proposing to undertake, and when he had been informed he notified the Institute that he would contribute $1500 of the appropriation toward the expenses which would be incurred. This is noteworthy as being the Federal Government's first grant—so far as we have been able to ascertain—in aid of scientific research for industrial purposes. Money had been appropriated to promote surveys and expeditions for the purpose of discovering the national resources, but this was the first occasion on which funds were set aside for the conduct of experiments, the results of which were problematical and might be intangible. Parenthetically, it might be stated that the outcome proved of such high value that one cannot refrain from expressing astonishment that the government remained so indifferent to scientific research until the crisis created by the Civil War forced the President to create the National Academy of Science, the members of which were to serve as scientific advisers to the government departments.

Rapid progress was made with the work. D. H. Mason was appointed supervisor of the experiments and "an experiment house" was occupied on the northeast corner of Vine and Twelfth Streets. The experiments were conducted with no little danger to those engaged, for the boilers were repeatedly taxed beyond the critical point. What the nearby residents thought about the proceedings is not a matter of conjecture. They protested energetically when the social amenities of the neighborhood were shattered by an unusually violent explosion.

A feature of this research of more than passing interest was the design and construction of apparatus for testing the strength of iron and copper. No such machine was known at the time in this country, so that it ranks as the first of its kind. The apparatus was held in such high esteem that, after it had served the purpose of the committee it was made accessible to anyone who cared to bring the material for test to the Institute. The apparatus is still preserved in the Institute's Museum, an interesting relic of American ingenuity as displayed more than a century ago and a lasting tribute to the zeal of those early members who created the research traditions still animating the laboratory research staff.

Some of those men who had examined the remnants of exploded boilers violently denounced the practice of riveting on boiler heads, a practice they contended weakened the metal. The investigating committee learned by experiment that riveted joints were actually stronger than the sum of the shear strengths of the rivets. They ascribed this to friction between the riveted plates, thus correcting a popular misconception.

This committee on boiler explosions devoted four years to its researches, and its reports are to be found in the Journal up to the year 1836. A summary report in pamphlet form was issued.[6] The fundamental nature of the investigation and the high value of the conclusions reached are best summarized in the Report of the Secretary of War for 1872. Writing upon the subject of experiments made at Sandy Hook in the presence of army observers, the Secretary wrote:

> It is gratifying to know that the experiments which have led to the most reliable information hitherto possessed by the scientific world on this difficult subject were instituted and conducted by an American institution (The Franklin Institute of Pennsylvania), under the patronage of our government, over thirty years ago. Those experiments were detailed in two able reports; one made in January 1836, on the manifestation of steam under various conditions and its effects, as steam, upon a small model boiler constructed for the purpose; and the other, made some months afterwards, on the strength of materials employed in the construction of steam boilers. The former report was published in Ex. Doc. No. 162, first session, Twenty-Fourth Congress; the latter, in Ex. Doc. 18, second session, Thirtieth Congress, included in a special report of the Commissioner of Patents. It is to be regretted that the experiments thus auspiciously commenced had not been continued until a complete solution of the difficulties could be obtained. No material advance seems to have been made in real knowledge on the subject since that time.

At the conclusion of this committee's labors, the Institute furnished the Senate of the United States the draft of a bill which was enacted, and became the law governing the inspection of boilers and engines of steamships. While this step had been taken in the right direction nothing was done toward providing regulations for the inspection of stationary engines and their boilers. This matter occupied the minds of Institute members for the next thirty years. Almost every issue of the Journal during that time contains one or more reports of boiler explosions at home or abroad, and members of the Committee on Science and the Arts visited the scene of all local occurrences in order to ascertain the cause. The city of Philadelphia was then in the forefront of industry and, in consequence, appeared to have a disproportionate number of boiler explosions. Many of these could have been prevented had there been any intelligent

regulation and enforcement of inspection. Eventually, with the continuation of preventable accidents and under pressure from the Institute, the city council was compelled to take action. The Law Committee requested the Institute to draft an ordinance which, when enacted, would ensure adequate technical provisions for observance.

A special committee was appointed in 1867 to study several drafts which had been submitted and work was proceeding in this when a terrific explosion in a local woodworking plant, in which 25 men were killed, demonstrated the criminality of any further delay in the passage of protective regulations. This last tragedy was one that could easily have been avoided since it was caused by the common practice of having one safety valve on two connected boilers. The draft ordinance which the Institute provided was quickly adopted and inspectors were appointed to see that its provisions were enforced.

During the Civil War, the President and the service departments were inundated with ideas advanced by patriotic citizens to improve the armament, ships, and navigational methods then prevailing. In order that competent minds should be employed to sift the grain from the chaff, the President created the National Academy of Sciences, to whose members all technical problems relating to the government departments might be referred for investigation and advice. A joint commission composed of representatives of the Academy, the Navy department, and The Franklin Institute was appointed in 1864 to investigate and compare "the results practically to be obtained by different measures of expansion of steam." This commission had its origin in the belief held by B. F. Isherwood, Chief Engineer of the U. S. Navy, that there was no advantage to be gained "in the use of steam expansively in steam vessels," an opinion that was vigorously opposed by other engineers. As was so frequently the case in pioneer efforts at research, the investigators discovered that no apparatus existed to assist in making experiments. As was customary the Institute representatives on the commission reported progress in their labors at the stated meetings. On the presentation of their second report, in which no results were announced because the reporter was restricted to an account of the apparatus devised for the experiments, a lively debate ensued among the members. Opposition centered upon the employment of a special dynamometer and not to the causes indicated.

The nature of this discussion is indicative of the keen interest displayed by Institute members and of their qualifications to undertake investigations of this nature.

In those early days of steam engineering, builders were accustomed to specify in the contract of sale, that their engines and boilers were of certain size and horsepower. That the engine came up to contract in the specified size could easily be determined with a foot-rule, but the horsepower delivered by the boiler furnished the basis for a very considerable divergence of opinion between buyers and sellers. In 1871 an appeal was addressed to the Institute inviting the members to establish a standard acceptable to buyers and sellers. As this was a vexing question it was decided to conduct experiments to ascertain how the horsepower should be determined.

Tests were made with two boilers known as double tank, with separate furnaces, each boiler having 500 sq. ft. of heating surface and 16 sq. ft. of grate surface. These boilers had been purchased by a local firm whose representatives had demanded a test by indicator, to which the seller demurred. As an incidental outcome of the Institute tests, the seller had to provide an additional boiler before the specified 100 horsepower was delivered. From this

one may judge the extent of the divergence of opinions and the necessity of a standard which the Institute now proposed to establish.

In an interim report, the special committee reviewed the origin of the term "horsepower" and the methods of measuring nominal, indicated, and actual power. They expressed a belief that uncertainty would be removed if the horsepower were to be specified in terms of the weight of fuel to be used per horsepower developed (that is, per cubic foot of water evaporated per hour). They also recommended that the term horsepower applied to a boiler should invariably be qualified as nominal, indicated, or actual in all ratings, and deprecated the practice then in use of rating a boiler's horsepower from the amount of work performed by the engine it operated.

The committee, meanwhile, pursued its research for the purpose of establishing a reliable method for calculating the heating surface required to evaporate a cubic foot of water in different types of boilers. Having collected information from numerous sources they were able to present a convincing comparison of the performance of the various types of boilers in use.

WEIGHTS AND MEASURES

However, steam boilers and steam engines did not exhaust the research activity of the members. When the Commonwealth of Pennsylvania was confronted in 1834 with the need for enacting a statute authorizing the provision of "metallic standards" to facilitate the inspection and regulation of the weights and measures in use, a copy of the proposed bill was submitted to the Institute with the request that its members make an investigation into the whole subject and to submit such amendments as they thought necessary to make the Bill effective. After a close examination of the systems adopted in the United States, Great Britain, and France, the committee which had been appointed raised objections to the projected legislation and, as an alternative, offered a Bill containing provisions for a system of weights and measures, and a supplementary Bill establishing the legal denominations which more closely conformed to other standards adopted in the country. The suggested Bills were adopted, and the legislature invited the Institute to supervise the construction of the standard units.

It is noteworthy that the manner of approaching this problem was adopted thirty years later when a committee of the National Academy of Sciences was requested by Federal authorities to inquire into the wisdom of adopting the metric system of weights and measures. The two methods of investigation were identical.

GAS LIGHTING AND HIGHWAYS

The prophets were not without honor in their own city. Many of the citizens had raised a violent protest against the proposal to introduce gas lighting. It was condemned on the wildest assumptions to be a menace to public health. The city councils adopted a more enlightened view but with lack of empirical knowledge could only meet assumption with counter-assumption. Finally, it was decided to dispatch Samuel Vaughan Merrick, moving spirit in the founding of the Institute, and a member of its Board of Managers for 22 years, on a tour of inspection of those European cities which had adopted gas lighting. It was upon Merrick's recommendations that the city gas works were

built and the system of street lighting was designed.

In the year 1843 the Select and Common Councils of the city presented a joint resolution to the effect that "The Franklin Institute be requested to communicate to the Councils any information they may think proper, in relation to the best modes of paving highways." With a diligence equalling that of all the other special committees, that which was set up to deal with this problem plunged into its work, interviewing experienced men, writing to various other cities with heavy traffic, and generally assembling all available knowledge on asphalt (just introduced in Paris), wood, and stone-block paving. While this material was being gathered and correlated, members of the committee made a survey of the soil and drainage of the streets. The report presented to the Councils made recommendations for the suitable paving of first and second class highways, drew up the necessary plans and specifications, offered suggestions for the superintendence and the manner of executing the work, and tendered an estimate of the costs.

STRENGTH OF MATERIALS

The Committee on Science and the Arts was still actively engaged upon the investigation of individual problems submitted to them. They rarely departed from the practice of examining new inventions or processes. This work did not involve the conduct of original experimentation, but, in 1844, this committee was asked to conduct an impartial investigation into the causes of an explosion of a gun on the frigate *Princeton*. This vessel was the object of unusual interest at the time she was launched since she was the first ship of war to be fitted with a screw propeller and carried two 12-inch guns, the most formidable weapons that had been constructed. The trials of this unique vessel were converted into a festive occasion through the presence of the President, John Tyler, members of his cabinet and Congress, and other distinguished visitors. One of the monster guns exploded, killing the Secretaries of War and the Navy, several other guests, and the men of the gun crew.

It is uncertain how this investigation came to be referred to this standing Committee but, judging from the facilities provided for the members, there is little reason to doubt that the terms of reference issued from official sources. Inquiries into the strength of wrought iron guns had been conducted previously by officers of the armed forces, but the investigating officers had restricted their reports to evidence obtained in firing tests. It seems clear that there were no data existing to enable them to form any conclusion upon the qualities of wrought iron other than what they could extract from the visual examination of the fractured parts when a gun had the misfortune to burst. The passages quoted to support the conclusions were, for the most part, taken from a French treatise on artillery which appeared to be the standard work of reference for the Bureau of Ordnance.

As the Institute had accumulated a large volume of knowledge on the strength of materials, due to its possession of the famous apparatus designed for this work, it seemed logical for the Federal Committee on Naval Affairs to turn to it for information on the strength of wrought iron and for an opinion upon the suitability of the material employed in the construction of the 12-inch guns, the explosion of which had very nearly robbed the country of its principal leaders. Without some overall official sanction it is improbable that the Committee would have been granted the privileges it enjoyed.

The members of the Committee visited the *Princeton* to examine the exploded gun. At their request they were furnished with a portion of the original metal from which the gun was made and they were given detailed information on the methods and processes employed in its construction. The members were of the opinion that errors had been made in the choice of metal, in its working, and in its welding. They declared that wrought iron should not be used in the construction of guns of large caliber until knowledge of its treatment had expanded. As was customary in established practice the Committee's conclusions were reinforced by an impressive array of results obtained in practical tests and in comparisons between the gun-metal and other specimens of wrought iron. The apparatus designed for testing the strength of boiler plate was used freely to test the resistance of the gun-metal in its bar form at different stages of its fabrication, and of sections cut from various lengths of the exploded barrel. The Committee disclosed that they had made a group of tests by which their knowledge of heat treating had been expanded, but the results were omitted from their report as the matter lay outside the terms of reference.

Professor Joseph Henry of Princeton University was a member of this committee. From observations made upon the nature of the fractured metal he resolved upon conducting a series of experiments which ultimately led him to form a theory upon the conservation of energy which, had he been able to overcome an innate dislike to publishing the accounts of his researches, would have established his reputation as a pioneer in this field.

SHIP PROPULSION

During "the roaring Forties" the whole country was humming with the sound of whirring wheels as machine-made goods began to replace the products of handcraft. New inventions were urged upon the buying public supported by most extravagant claims. Some spirited discussions were opened when two types of product entered into open competition. One of these discussions centered upon the relative merits of propellers and paddle-wheels for steamship propulsion. This question began to assume an additional importance when the public mind became agitated over the inauguration of mail steam services in Britain and the proposals for an increased steam navy at home. Government bureaus were still without research departments and since the Institute had established a reputation for competent researches and impartial judgment, the Secretary of the Treasury, Robert J. Walker, appealed to the members for an unprejudiced opinion upon the subject which had sharply divided maritime circles. Specifically, they were to supervise tests made with Hunter's submerged paddle-wheels and Loper's propellers.

They were presented with a report of trial-runs made by the *Spencer* in New York Bay in 1844, in which both types of propulsion had been tested. This report was carefully analyzed and some theoretic conclusions deduced. The members of the committee then accompanied the vessel and the *Water Witch* on some additional trials of a more exhaustive nature between New Castle and the Delaware Breakwater, in which the paddle-wheel and the propeller were interchanged. The results showed that with the same power Loper's propeller was 4.6 times as efficient as the submerged paddle-wheel, an empirical result that agreed with theoretical anticipations.

LIGHTHOUSES

Shortly after his installation as the Secretary of the Smithsonian Institution, Professor Joseph Henry was appointed to the Lighthouse Board. It was a lamentable fact that coast-wise lights had fallen far behind those of Europe, so that an experienced physicist had little difficulty in finding opportunities for improvement. One of his first recommendations was that Fresnel lenses be installed in all the lighthouses to secure improved illumination. Four models of the proposed installations were exhibited at a stated meeting of the Institute, April 19, 1849. These attracted so much attention that a committee was appointed to investigate their properties and to compare them with the lights in general use. The report lacked nothing of forthrightness in condemnation of the lights in use which, it was declared, were so inferior to those introduced into European lighthouses, as to be unworthy of comparison. The committee members expressed themselves strongly in favor of the Fresnel refracting lenses, ruefully recording that only one light of this kind had been installed in this country while the coasts of Europe were lighted by 300. After collecting and analyzing a considerable amount of technical information upon different types of lenses, the members expressed the pious hope "that our whole coast, on both oceans, and on the lakes, may speedily be provided with this brilliant, economical and admirably devised gift of the science and art of the Nineteenth Century."

This report must have enheartened Professor Henry, who was under strong pressure from members of Congress urging the claims of their supporters to have their products purchased out of public funds. The approval of a highly respected technical body furnished him with strong moral support in his efforts to secure a greater degree of safety for mariners.

FIRES IN THEATERS

The years 1850-1852 were marked by an increase in the numbers of fires, which had caused the destruction of much property and loss of life. When the attention of Institute members was drawn to this situation by one of their number a committee was appointed to prepare a memorial to be submitted to the Common Council of Philadelphia in the name of the Institute recommending the passage of an ordnance which would not only prohibit the erection of wooden buildings, but would determine the height, thickness, and materials for the walls in order to reduce the ravages of fire.

This was the introduction of a subject which, like that of steam boilers, was to receive attention intermittently for thirty years and was to end by an investigation which was to have far-reaching effect.

In 1853 the firm of Jos. S. Elkinton and Sons had a factory destroyed by fire. Three years later the firm had another fire, caused apparently by spontaneous combustion of sawdust. The firm appealed to the Institute for an opinion upon the question: Would sawdust situated forty feet from any flame ignite spontaneously? Investigation revealed that the sawdust was packed around a tank for rendering grease. The sawdust had been in use for about nine months and the tank was heated by steam at about 50 lbs. pressure to the square inch, equivalent to a temperature approaching 301° F. The members of the Committee found a report of a fire in London where the conditions had

been almost identical, and this led them to conclude that the sawdust, charred by the distillation of moisture and volatile matters in the wood, at low temperature was more highly inflammable than normal sawdust at a higher temperature. The Committee recommended that builders be cautioned against allowing joists to run near flues, through hot air chambers, or near boilers and steam drums.

The nation continued to be shocked by conflagrations involving a heavy loss of life. The number of fires in theaters and public halls in the United States was out of all proportion to those experienced in other countries. A member, C. John Hexamer, presented a paper before the Institute on the subject and the members present were so impressed by his material and, realizing the inadequacy of the protective measures he advocated, decided the subject was of sufficient importance to be worthy of more comprehensive investigation. They appointed the usual committee to undertake the necessary research and to submit a report that would contain recommenations for preventive measures which would insure a higher degree of safety for audiences and property.

The special Committee pursued their investigations over the period of a year, but their time was well spent, as is apparent from their report,[7] which is a model of its kind. It should be remembered that the members of the Committee were confronted with conditions which differed materially from those prevailing today, but many of the recommendations contained in their report as obligatory were so fundamental that they are universally applied today as essentials to public safety and the preservation of property. The greatest number of fires in theaters originated in the lighting apparatus, which was either coal gas or, in the United States, coal oil. The Committee was emphatic in endorsing the new incandescent electric light, the installation of which was regarded as the most necessary reform in theater construction. The members condemned the use of coal and wood stoves for heating the buildings. After six months of experimenting to discover a suitable process they recommended the impregnation of the scenery materials to render them fireproof. As proof of the exhaustive nature of their work, they mentioned that they had tested all the types of fireproof paint on the market before approving the method recommended.

All the workshops and paint lofts were to be banished from the theater proper and iron doors were to be provided to add to the physical separation. Then follows the recommendation for the universal adoption of the fireproof asbestos curtain. This adjunct to safety had not been tried in this country but the Committee initiated their own experiments with woven asbestos and made a final large scale test at the Brooklyn Navy Yard which convinced them that the asbestos curtain was an essential in all theaters. As a precaution for isolating the fire, should there be an outbreak while the theater was unattended or when opening for a performance, it was recommended that the curtain remain lowered until within fifteen minutes of the performance beginning.

Altogether, thirty-eight precautionary measures were recommended. Many of these did not deal with new materials which had become available but were the application of common sense principles to the provision of greater safety. The marking of all exits with illuminated signs; the opening of all doors outward on the street; the abolition of long unbroken rows of seats in favor of adequate aisle spaces; the fixing of all seats to the floor with spring attachments to throw back the seat when it was not occupied; the use of hair instead of paper wads in fire-arms used on the stage; and the provision of an automatic sprinkler system were among

the other precautions recommended to reduce the danger of an outbreak of fire and to facilitate the prompt departure of the audience should a fire break out. The public authorities were not excluded from their share of responsibilities in regard to the observation of proper precautions, since the appointment of qualified persons to see that the precautionary measures were enforced, together with a brief outline of their duties, was incorporated in the recommendations advanced in the report.

In this report we have the genesis of a safety code for the construction and equipment of theaters and public halls compiled with such foresight that the majority of its provisions have survived the passage of time.

Not all the research undertaken by the Institute was of such general significance. One diversion from the broad highway of social progress into a by-path was offered when the roof of a church on Eleventh Street above Spring Garden, Philadelphia, collapsed without warning in 1852. The minister of the church appealed to the Institute for advice, so that when reconstruction was begun any structural defect in the original might be remedied. As there was an obvious public service to be gained in an inquiry of this nature where safety of audiences and congregations was involved, the subject was accepted for investigation. Models of the roof and two of the trusses (⅛ scale) were made, and weights were applied until signs of fracture were observed. From calculations made as a result of these experiments it was found that a roof weighing 30,000 lbs. had collapsed when the trusses were designed to support more than twice that load. Attention was then given to the timbers and an examination showed them to have imperfections in too numerous knots. Moreover, the timbers had been cut across the grain, which it was judged rendered them unsuitable for the purpose to which they had been put. It was also pointed out that the danger of a heavy snowfall had not entered into the calculation of the roof supports. It was recommended that the trusses should be designed to support not less than three times the weight of the roof.

SCREW THREADS STANDARDS

A task of much greater importance was assumed in 1864. The president of the Institute, Williams Sellers, read a paper on "A System of Screw Threads and Nuts," in which he deplored the prevailing practice of manufacturers in following their individual caprices when designing screw threads. He pleaded that some consideration might be given to the speed and ease with which an engineer could replace a defective or broken screw and nut. The speaker wasted no time upon describing the abundant variety to be found among American screws and their threads, for his hearers were fully informed upon the disadvantage of the lack of standards which complicated their repairs. The audience responded to his plea that the Institute should take the lead in advocating a uniform system of screw threads on the lines of the British example in that field. A Committee was promptly appointed to draw up a system of standards which would meet American requirements.

As this committee's researches progressed, the members were greatly impressed by two features they had not contemplated. First, the variety of screw threads in use was so much greater than was thought that a standardized system, if adopted, would effect economies far beyond their expectation. Second, the interest displayed in their labors indicated that success with the standardization of screw threads would induce the extension of standardization

to other manufactures. From this latter observation may be inferred the reason why the Institute was in the forefront of the agitation for the establishment of a national Bureau of Standards.

The committee's report was sent to the Chiefs of Ordnance of the Army and Navy, the Quartermaster General, the Chief of the Engineering Corps, the superintendents and master mechanics of railroads, and all mechanical and engineering societies with the request that they support the movement for the general adoption of the system and to require that all construction under new contracts should be carried out in accordance with the provisions of the recommended standards. The government departments promptly adopted the system. In 1872 the Master Car Builders' Association adopted it as their system of standards and so hastened the action of those railroad companies that had deferred embracing uniformity. Eventually the system met with general acceptance and what had been known as the Franklin Institute system became the United States Screw Threads Standards.

The Institute was now committed to so much research activity, either by members of the special committees appointed as occasion arose or by the Committee on Science and the Arts that the facilities afforded for the conduct of experiments were quite inadequate. In presenting the annual report for the year 1865, the President spoke proudly about the improvements which had been made. After mentioning the improvements carried out in the Lecture Hall, he commented upon the laboratories adjoining that room, which had undergone extensive repair, had been furnished with new cases for apparatus, and had been provided with both gas and water supplies. "An evaporating closet . . . to answer efficiently to the demands of modern experimentation" had also been added. One of the rooms had been converted into an efficient dark room. Ten years later, in response to the demand, a new and improved machine for testing the strength of materials was purchased. The modest hopes of the founders that the Institute should have an "experimental workshop" were being realized.

LIGHTNING PROTECTION

The Institute had acquired a merited reputation for its interest in the public welfare, and local authorities repeatedly sought its assistance when confronted with technical problems. In the year 1866 the city council asked for advice upon an adequate system of protection against lightning for the Blockley Alms-House. As most of the members were acquainted with Franklin's work upon lightning rods, no special committee was needed for this problem, which was referred for quick action to the standing Committee on Science and the Arts. The report presented by this committee is noteworthy because of the care devoted to fundamentals as well as to the specific needs, special attention being devoted to the height and number of rods so that the entire group of buildings was protected. The care taken to insure the safety of a long structure would serve as a model for a phase of lightning protection which is still neglected.

RAILROAD SIGNALS

It will be clear from what has been written that the researches promoted by the Institute were largely devoted to the regulation of dangerous practices accompanying the rough and tumble development of new industry, and to the removal of hazards which were making progress expensive in human

life and property. One of the most notable expansions in the growing nation had been in the railroads, which had mushroomed and were destined to undergo a feverish promotional activity after the War between the States. Just as in our days when the individual States cling to capricious automobile regulations to the perplexity of visitors, the newly developed railroads had their own ideas upon dangers and the signals to be employed in avoiding them. This caused much confusion and a number of accidents arose from mistaken signals. Members of the Institute perceived the need for the adoption of a uniform code of signals acceptable to all railroads and, with rare foresight, declared that unless uniformity was achieved the danger of the existing variety would be increased as the railroad systems expanded, as they did with astonishing speed. Following the usual practice a special committee was appointed to draw up a code of signals which was to be presented to Congress for incorporation in a Bill establishing uniform signals on all the railroads in the country.

The manual and whistle signals between conductor and engineer were defined; the ringing of a bell when the locomotive was leaving a station was to be made obligatory; the train crew was to be responsible for placing detonators behind a stalled train; and many others of the familiar signals were included in the code. The provisions of the code were enacted into law and have existed to the present time with one exception. Green lights and flags have replaced the white which was recommended.

ASTRONOMY

The next research group was to invade entirely new scientific territory. The total eclipse of the sun which was to occur in 1869 excited a great deal of interest among the members, who petitioned the government to appropriate funds to permit its observation. The official response was inadequate. The members thereupon resolved to organize a group of volunteer observers under the direct supervision of the Resident Secretary, who was to coordinate their efforts with the national observers under the superintendent of the *Nautical Almanac*. The group, known as the Philadelphia Photographic Expedition, centered its activity on Burlington, Iowa, and equipment was collected from various sources so that three observing parties might be formed, each equipped with a 6-inch telescope and photographic apparatus. The tasks of the three groups had been well organized and the results obtained were gratifying. Satisfactory photographs were taken at various stages of the eclipse, and some excellent pictures were obtained of the corona.

In 1932 a second solar eclipse party was dispatched to Conway, New Hampshire. This party was unusually well equipped with cameras 85 and 40 feet long, motion picture cameras, coelostats, and pyrheliometric equipment. Unfortunately, the weather was not propitious for observation. Although the greatest care had been exercised in the choice of a location and the selection had been made after an intimate study of weather conditions, the site chosen chanced to be one from which only few photographs could be taken because of clouds.

PETROLEUM

After the successful drilling of the first oil well in Pennsylvania the use of petroleum spread rapidly. The refining methods were primitive and by no means as efficient as they were to become. As a natural consequence a number of oils were marketed for domestic illumination which had dangerously low flash points.

The widespread and careless use of these oils by persons ignorant of the inherent dangers led to an unusual number of fires in which individuals lost their lives or were severely burned. During the year 1871 the number of outbreaks increased by 40 per cent to the general alarm of the authorities. The apprehension of unrestrained casualties attributable to this hazardous form of indoor lighting stimulated the Institute members to inquire "into the causes of conflagrations and the most efficient methods of prevention."

Investigation of the oils on the market brought to light the popularity of an oil containing appreciable proportions of benzene and naphtha because the inclusion of the volatile elements caused a brighter flame than the more stable but safer oils. The state inspectors were authorized to inspect only coal oil and kerosene. Anything that was sold under other names was free from their condemnation however hazardous it might be.

The research committee appointed to investigate the question presented two reports. One of these, signed by the Institute's secretary, Dr. William H. Wahl, reflected what was by far the most intensive study of the light petroleum oils that had been made up to that time. The hazards accompanying the indiscriminate use of these lighter oils were so clearly demonstrated that the other members of the committee recommended that the State Legislators pass laws to restrict their sale and to give powers to the inspectors to condemn any lamp fuel which did not accord to the committee's definition of a stable lamp oil. The Legislature was not slow to act upon this expert advice upon the means of curbing the increase in household disasters.

ELECTRICAL ENGINEERING

The use of electric power began to intrigue members of the Institute at an early date and in 1877 it was proposed to purchase "a Dynamo-Electric machine capable of producing not less than 1200 candles' light." Reverting to the experience of boilers where sellers and buyers were prone to have divergent views upon the power produced, the members proposed to invite makers to send in their dynamos for practical tests. The members were not going to accept any dynamos on the strength of unsubstantiated claims, but the question arose: How did one test a dynamo?

Five dynamos were submitted for the comparative test which was to be conducted by a special committee whose members promptly divided themselves into three sub-committees responsible for different phases of investigation to make photometric, electric, and dynamic measurements. Five types of dynamos were subjected to test: a large and a small Brush, a large and a small Wallace-Farmer, and a Gramme. The selection of Elihu Thomson as a member of the investigating committee caused the elimination of his own efficient dynamo from competition. After exhaustive tests it was decided to recommend the purchase of the small Brush dynamo.

That portion of the committee's report which dealt with electrical measurements was a classic of simplicity and directness. It describes in detail the procedure followed, for it must be recalled there were no meters available for measuring voltage, current, or resistance, and the investigators had to work with galvanometer and Wheatstone bridge. The methods adopted were so admired that they were generally followed until the Institute issued the report of later research. When the first International Electrical Exhibition was organized by the Institute in 1884, the members proposed to take advantage of this unique assemblage of material to

establish a code for testing electric dynamos. For this occasion subcommittees were formed to conduct tests and to report upon the efficiency and duration of electric lamps, signalling apparatus, batteries, and telegraphs in addition to the dynamo tests. The various reports were published in successive issues of the Journal and later were collected for publication.

Some idea of the esteem in which the work of these committees was held may be gathered from the laudatory comment extracted from a contemporary journal.[8] "The tests of dynamo-electric machines, made in 1885, under the auspices of the Franklin Institute, are undoubtedly the most reliable and complete of all the impartial tests which have ever been made and published, and they therefore afford the practical engineer an excellent opportunity to deduce proportions, dimensions, and constants, to assist him in designing dynamos, especially as the machines which were tested are among the best that are made." The writer declared that the previous practice had been to build dynamos by guesswork and then to try them to "see what they will give," but that with the results of the Institute's research the machine could be tested in all its parts so that it can be constructed to give desired current and potential.

PAVING OF STREETS

About this time there was a revival of activity on further behalf of the local community. Recalling that the Institute had been instrumental in making a survey upon which arrangements might be made for the paving of the streets of Philadelphia, the city councils were dissatisfied with the condition into which the cobbled streets had fallen. They wished to have a thorough investigation made into the problem of the use of cobblestones.

Two expert civil engineers were named by the Institute to carry out this work and, as was to be expected, their report revealed a comprehensive study of the subject had been made. The cause for dissatisfaction with the cobbled streets apparently lay in the ineffectual method of maintenance and repair. Superior repair methods were defined. There were still many narrow streets in the city that had to bear heavy traffic (50 heavy wagons or trucks an hour constituted "heavy traffic"). For these streets, the experts recommended the substitution of granite blocks for cobblestones. In spaces around public buildings, hospitals, etc., where quiet surroundings were required, the pavement should be of sheet asphalt. Macadam roads were recommended for suburban areas. In each case detailed instructions were provided for the manner in which the materials should be chosen and the roadways constructed.

WATER SUPPLY

The Select and Common Councils of the city found themselves the storm center of an agitation growing out of the inadequacy of the city water supply and the pollution of its sources. The members of the Institute had already protested about the pollution of the Schuylkill River which was the principal source of supply and at the request of the councils had made an investigation of the various pumping stations and reservoirs. The Wissahickon, Perkiomen, and the upper Delaware Rivers were explored for the purpose of extending the sources of supply. But by 1885 the industrial development of the city had made the water supply inadequate and the Mayor was authorized to address a further appeal for aid to the Institute. A commission of five members was recommended, two of whom

were drawn from the membership, to conduct a thorough investigation of the entire subject of the water supply and to make recommendations which would provide for future needs. Their report contained specific recommendations for the installation of pumping machinery and subsidiary apparatus, the completion and extension of reservoirs, and the management of the stations. It is interesting to learn that the use of meters for the prevention of waste in factories and public buildings was among the improvements recommended.

SMOKE NUISANCE

A startling reminder that Philadelphia had become a prosperous manufacturing city was conveyed to the members when the Grand Jury roundly denounced the growing smoke nuisance in the city. With a sense of responsibility for the public welfare, the Institute members voluntarily took action and undertook an investigation of the situation in 1892, but their recommendations for the remedy of a growing menace to health did not animate any official interest. Five years later the situation had grown so much worse that the need for immediate action could no longer be ignored. The Board of Health addressed a request to the Institute for cooperation with a view to taking action which would achieve abatement of the smoke nuisance created by the increased use of bituminous coal in industrial plants. Among the recommendations made were those for a campaign to educate firemen and engineers in the proper use of their furnaces and to extend the use of anthracite.

LOCOMOTIVES

The reputation of the Institute's research committees for exhaustive and impartial treatment of controversial subjects gained for one of them the position more or less, of arbiters in a contentious railroad problem. This was a joint committee of the Institute and the American Railway Master Mechanics Association created to "investigate the hammer-blow, or magnitude and variation of pressure, of locomotive driving wheels, on the rails of a railway." The members of the Association were familiar with the diversity of opinion amongst leading engineers, many of whom contended there was no wave force, or so-called hammer-blow, from the imperfect balancing of the driving wheels. It is not improbable that these members were among the principal disputants, with the Institute members in the role of umpires.

The committee arrived at the conclusion that engines considered most perfectly balanced by counter-weights in the crank wheel did create a great disturbance in a vertical direction, causing a wave force that might be compared to a hammer-blow, that had a destructive effect upon rails and bridges dependent upon the weight and velocity of the moving parts. Having arrived at this conclusion, the members of the committee found themselves unable to measure the force of this hammer-blow, but they recommended strongly that steps should be taken to measure it and, in the absence of any appropriate apparatus, they designed a dynamometer which was believed competent for the purpose. As this would cost $6000 to build, it was suggested that the railroad companies, who would be the beneficiaries of the knowledge to be derived from it, might undertake to bear the expense. The suggestion was not followed but the problem of the hammer-blow increased so rapidily in significance that the railroads were compelled to seek a solution, which they did in their individual ways.

COMMITTEE ON SCIENCE AND THE ARTS

Allusion having been made to the Committee on Science and the Arts, it becomes necessary to say something more of its purpose and to indicate the wide nature of the research it had undertaken. From the time of its inception, this standing committee had accepted for study any scientific idea or invention submitted to it. A painstaking investigation was undertaken into the prior art in order to establish claims to originality; and, when these claims were found to be justified, the committee was ready to endorse any new method or device and to assist in obtaining for it a fair share of public recognition. This was an expert service welcomed by men who lacked the time or means to exploit the novelty of their ideas; and the committee was never without a number of cases, mostly concerning new industrial products awaiting their turn for study.

The scope of this committee's researches has been remarkably wide. Its approval would not have been so eagerly sought by applicants had not the integrity and ability of its members been above reproach. The high standard of judgment had been systematically sustained by providing a panel of members large enough to ensure that specialists could be chosen to form expert sub-committees. The reports of this committee published in the Journal over a number of years demonstrate the care with which every case was examined and the impartial manner in which the members rendered their judgment upon its merits.

Another factor of their work which should not be overlooked was the encouragement it gave investors. When this committee began its operations, men had not yet learned to invest large sums of money in such speculative enterprises as the establishment of factories, especially as costs for iron, the essential metal, were high and metalworkers were still scarce. When the Committee had submitted a process, a material, or a product to an exhaustive examination and tests, and had given it their approval, prospective investors had confidence in their judgment and became readier to furnish the funds needed by an inventor. The work of the Committee had removed much of the risk from the investment.

BARTOL RESEARCH FOUNDATION

When World War I broke out, the Institute had neither the staff nor the facilities to undertake research work of the nature required in that emergency, but its educational facilities were taxed to the utmost in the establishment of a school for teaching the newly developed science of wireless telegraphy to men of the selective draft; in administering a recruitment and examination center for applicants for the Aviation Service; and in conducting a school of navigation for the United States Shipping Board.

When that world conflict was drawing to a close, the Institute realized its long deferred hope to have a permanent staff of research workers. In 1918, Henry W. Bartol, a prominent local industrialist, bequeathed a sum approximating one million dollars for the establishment of a laboratory "for the conduct of researches in the physical sciences and for the investigation of problems of a scientific nature arising in the industries."

Actual work did not commence until 1925 in a group of converted dwellings in 19th Street at Race. This site proved to be unsuitable for the purpose and arrangements were made to transfer the laboratories to the campus of

Swarthmore College. Here, a building was erected by the Institute where the most sensitive instruments could be installed. Operations were opened in 1928 under the direction of Dr. W. F. G. Swann.

Mr. Bartol had expressed a preference for studies to be undertaken in the fundamentals of electrical science. It is abundantly clear by now that the fields of fundamental research are the incubating grounds for the ideas which supply the needs of industry, and that the older a science grows the deeper an investigator must probe to reach the fundamentals. As regards the fundamentals of electrical science it is impossible to disassociate the electrical concepts from all others bound up with nature's structure, and the student who does research on such a fundamental subject as atomic structure finds that the fundamentals of electrical science are inextricably interwoven in his studies. Before the outbreak of World War II the Bartol Foundation devoted its energies primarily to the study of matters pertaining to atomic structure and to cosmic radiation. Such investigations lay largely within the spectroscopic region and the region of nuclear physics.

With the outbreak of hostilities, the work of the foundation underwent some modification which has not been without its influence upon its subsequent labors, but the staff is devoting its main efforts to studies of particle nuclear physics; studies of cosmic rays; studies of electrical discharge in gases; and studies of electrical phenomena associated with the solid state. Development of such a program necessitated the building of certain new equipment in line with the requirements of the program. The Bartol Research Foundation now possesses four different types of high energy particle accelerators. One of these machines is comparable to the largest of its type in the world, and a new building has had to be erected to accommodate it and its accessories.

This, then, is an outline of the research work undertaken by The Franklin Institute during the first hundred years of its existence. We are what the experience and actions of a lifetime make us. If this is true of men and women, it is no less true of institutions, and to understand fully a great organization one must know its past and watch its progress of growth and development. During its long history the Institute has passed through a succession of changes in which the pattern of life, both national and individual, has undergone a fundamental change. In spite of violent economic upheavals, mighty wars, and revolutionary discoveries in science, certain characteristics of the Institute's work have remained constant. As other institutions grew and conceptions of responsibility were modified, the Institute relinquished those functions which could be discharged more appropriately in other hands. The tradition of research by team work has survived throughout the changing years.

In the beginning it was necessary to perform only the simplest functions which would enable manufacturers to achieve a position in a swiftly moving economic transition, but large and wider liabilities were voluntarily assumed and supported during the changing years. After equilibrium had been attained, the needs which had to be met were different, new and improved things were constantly sought by industry. Finally, we have arrived at a stage where it becomes increasingly apparent that the choice of what research organizations undertake to do and their capacity for performing their work efficiently are dictating much of industrial policy. The measures which the Institute has taken to adjust its research policies to the needs of the times are reflected in the fully equipped laboratories for research and development which now have been established. The adventure in research which these laboratories afford would

provide a technical writer an endless source of material but, as Kipling said, that is another story. Our purpose has been to describe the pioneer work. The Institute laboratories of today are following an ideal set more than a hundred years ago and pursued thereafter consistently by the members. From the beginning it has been recognized that the primary responsibility for all experiment, research, and development is to industry which it serves.

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3. J. Smeaton, "An experimental Enquiry concerning the natural Powers of Water and Wind to turn mills and other Machines, depending on a circular Motion," *Royal Society Philosophical Transactions,* Vol. LI, Part I, 1759, p. 100.

4. These were the successors of Oliver Evans who had done so much to develop the steam engine.

5. "Communications received by the Committee of The Franklin Institute on the explosion of steam boilers," Philadelphia, The Franklin Institute, 1832, 32 pp.

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8. Carl Hering, "Practical Deductions from The Franklin Institute Tests of Dynamos," *The Electrician and Electrical Engineer,* November, 1886, p. 423.

NOTES ON THE HISTORY OF THE GENERAL EQUATIONS OF HYDRODYNAMICS

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MR. C. TRUESDELL, of the Graduate Institute for Applied Mathematics, Indiana University, wrote this article, which was published in the August-September 1953 edition of "The American Mathematical Monthly."

INTRODUCTION

The following article consists mainly in the descriptions of volumes in an exhibit in the Indiana University Mathematics Library commemorating the two-hundredth anniversary of the general equations of fluid dynamics.

1752-1952. In 1748 the Berlin Academy proposed as the subject for the prize competition of 1750 the theory of the resistance of fluids. The tentatives of Newton were known to be wrong, and nothing but empirical formulae had taken their place. The subject, besides being close to the unexplored foundations of the concept of inertia, was thus of great mathematical interest and practical moment.

In December, 1749, d'Alembert sent to Berlin his entry, a long *Essai d'une Nouvelle Théorie de la Résistance des Fluides.* The Academy, of which d'Alembert was a non-resident member, judged that no contestant had earned the prize, sent back all manuscripts, and urged the authors to compare their predictions with the results of experiment. D'Alembert withdrew at once, and in 1752 he published his essay. It is described in §3 below. In the introduction d'Alembert details the circumstances in angry and sarcastic terms.

At the time of the contest Euler was director of the Mathematical Division of the Berlin Academy. It seems difficult to believe that he could have expected seriously that a theory of fluids could give results in accord with existing experiments on the resistance suffered by submerged bodies. The data itself was confused and sometimes contradictory. Nearly all the experiments concerned turbulent flow; they were not to be understood even qualitatively for a full century following; and to the present day the phenomenon of resistance remains, as far as any rigorous theory is concerned, a partially open question. Rather, it is likely that the reason given

out was only a pretext, offered in place of the truth, much more difficult to substantiate to an author, that d'Alembert's reasoning was tortuous, incomprehensible, and endless, and that in illustration of his equations he had not succeeded in exhibiting a single two-dimensional flow.

This view is supported by the fact that by 1752 Euler had read to the Academy a paper *De motu fluidorum in genere*, treating this subject. Enestrom * identified this paper with that described in §4 below. No resistances of specific bodies are calculated in it, nor in any of Euler's papers on the general theory, and there is no attempt to compare predictions with experimental measurements. But much that d'Alembert had tried to do is achieved in a direct and economical fashion, not only more general but also far more convincing—as Euler said in a later paper, "directly from the first axioms of mechanics."

It was the facile opinion of Euler's contemporaries, repeated in most of the present histories of mathematics, that † "M. Euler seemed sometimes to be occupied by the pure pleasure of mathematical calculation and of considering the questions of mechanics and physics only as occasions for exercising his genius and for abandoning himself to his predominant passion. So scientists have reproached him for having sometimes lavished his calculus on physical hypotheses, or even on metaphysical principles, of which he had not sufficiently examined the likelihood and solidity." In contrast, d'Alembert is represented as a physicist who "explained with his usual clearness and insight the necessary dependence of calculation upon experiment." This estimate of d'Alembert seems to derive from Lagrange, who in various places in the *Mécanique Analytique* attributed to d'Alembert various things which it is extremely difficult to locate at all in the actual writings of d'Alembert himself, and extremely hard to follow even when located. I believe that any modern scientist who actually reads the papers of d'Alembert and Euler will soon adopt a directly reversed view. In fact, in theories of nature Euler was so superior to all his contemporaries that parts of his writings on mechanics and physics were dismissed as too "mathematical," while to the modern reader they appear perfectly clear and in large part correct. It should be added also that Euler not only kept himself fully informed in experimental physics, but was always ready to make immediate use of the results of his calculations—and moreover, that those of his hydro-dynamical writings which made the greatest permanent advances are those least influenced by experiment, while those in which he compromised with practicality have lost all but historical interest, since the experimental data available was obscure, incomplete, and sometimes faulty.

The work of d'Alembert in hydrostatics was examined in detail by Todhunter, who found it "almost uniformly wrong" and containing "but little of importance." After careful search of his writings on hydrodynamics, I find the same words applicable, except for the fact that he did somehow arrive at the correct equations for plane and axially-symmetric irrotational flow. Philosophical meandering and doubts regarding the validity of the theory he is constructing fill so great a part of his work that there is little space left for development of the theory itself. It is quite possible that d'Alembert's discussion of experiments and repeated criticism of the mathematical method in physics may have appealed to some physicists of his day, as doubtless in ours; but no progress, either in mathe-

* Verzeichnis der Schriften Leonhard Eulers, *Jahresbericht der deutschen Math. Verein.*, 4 Erganzungsband, 1910.

† Éloge de M. Euler (by Condorcet), *Hist. Acad. Sci. Paris*, 1783, (1786).

matics or in physics, was achieved by these merely negative statements.

1. I. Newton, *Philosophiae naturalis principia mathematica,* London, 1687. Newton's views on fluids were heterodox. In the *Principia* we find both a molecular model of a "rare medium, consisting of equal particles freely disposed at equal distances from each other," and side by side with it a representation of a fluid as a smooth continuum without voids. The former view, in which impacts of the fluid particles upon each other and hence also those upon the back side of a submerged body are neglected, led Newton to the famous law of resistance proportional to the square of the velocity, and to his difficult and incorrect theory of sound. It has excited a great deal of notice ever since 1687, but has not led to any significant development in hydrodynamics.

One of the several passages where fluids are regarded as continuous media may be found in Lib. II, Sect. IX. Here Newton states a "Hypothesis," which may be translated as follows: "the resistance arising from the want of slipperiness in the parts of a fluid is, other things being equal, proportional to the velocity with which the parts of the fluid separate from one another." It is the earliest correct statement regarding the internal friction of fluids. When properly generalized by Stokes (see §10), it forms the basis of the modern theory of viscosity. Theorem 39, however, which follows immediately, is false, as is virtually every specific conclusion of Newton concerning fluids.

Historical research has destroyed much of the attribution of originality to Book I of the *Principia,* where occurs much of the now standard material given in elementary mechanics courses. This part of the treatise now appears mainly as an attempt at organization and rigorous, deductive treatment of known material. Earlier works contained errors freely intermingled with correct results, while Newton's presentation is correct in principle and in detail. Book II, however, which concerns the properties of fluids and of bodies moving in them, consists almost entirely in original work of Newton, who was the founder of hydrodynamics. The plan of deducing everything from the axioms, so distinctive a feature of Book I, is abandoned, and fresh hypotheses are put forward at every turn. We may gather from a remark in the preface that it is necessity, not choice, which has enforced this breakdown of the original scheme. Newton's might of intellect is revealed even more clearly in this largely erroneous but path-breaking part of the work, which gave rise to two hundred years of controversy in the attempt to correct and complete what Newton had begun. Finally, in Book III Newton shows his peerless ability to get specific, numerical conclusions from an analytical theory and to compare them with the results of experiment.

2. D. Bernoulli, "Theoria nova de motu aquarum per canales quoscunque fluentium," *Commentarii Academiae Scientiarum Imperialis Petropolitanae,* 2 (1727), 111-125 (1729). The word "hydrodynamics" was created by D. Bernoulli with the publication of his *Hydrodynamica* in 1738. The Indiana University Library does not possess a copy of this book; exhibited instead is a paper, published a few years earlier, which may serve as a specimen of the methods and results.

No general equations or general principles of fluid motion are to be found here. The *Hydrodynamica* is famous for "Bernoulli's theorem,"

$$p + \tfrac{1}{2}\rho v^2 = \text{const.},$$

which is taught in every freshman physics course. In this simple form, however, it is not to be found in the book, nor is its use given any prominence. In both the journal article (p. 112) and the book the analysis rests on

the "principle of the conservation of living forces," which Daniel Bernoulli attributes to his father, John Bernoulli. At this time there was a vigorous general controversy regarding *vis viva* (kinetic energy). In the book, the conservation of energy is asserted in the form of the "principle of equality of potential ascent and actual descent." The terms are defined as follows:

"We shall note that the *potential ascent* of a system whose several particles are moved with an arbitrary velocity signifies the vertical altitude which the center of gravity of that system would reach if the several particles are conceived to turn their velocities upward and rise as far as they can; that the *actual descent* denotes the vertical altitude through which the center of gravity descends after the several particles had come to rest." The book was praised by Lagrange as "a work which shines with analysis as elegant in its ordering as simple in its results."

The "Bernoulli equation" in its now usual simplicity was first written down by Euler (see §4, 5), who derived it as an integral of his general hydrodynamic equations. In so doing, he generalized it in three ways, obtaining the forms valid in unsteady potential flow, in barotropic potential flow, and (with the constant generally assuming a value differing from one stream-line to another) for steady rotational flow.

That Daniel Bernoulli did not attain the simplicity of a modern engineering treatment, while Euler, beginning with a much more elaborate mathematical structure, by purely analytic manipulations attained the result in its now customary form, should not astonish us. Daniel Bernoulli wrote not only before Euler had made it customary to express general physical principles as mathematical equations, but also before the concept of internal fluid pressure had been created. His hydrodynamical works consist of long sequences of special problems ingeniously solved by means of the energy principle. Many of these problems are of the type which can be treated somewhat more simply nowadays by use of what is now called "Bernoulli's theorem." His father, the old John Bernoulli, in envy at his son's success immediately wrote his *Hydraulica*, pre-dating it by seven years so as to make his son appear a plagiarizer. Nevertheless, the new work was enthusiastically praised by Euler as the first to use the "true and genuine method" and to be based on "the most certain principles of mechanics." By the former Euler meant the method of infinitesimal elements; by the latter, the momentum principle. In John Bernoulli's treatise we find also the first rather rough use of internal pressure, and the first actual equation equivalent to a fairly general case of the modern "Bernoulli equation." All this work concerned flow in tubes, and in Euler's early hydraulic papers the greater generality of the problems treated led to forms of the result gradually approaching the modern one.

The paper of Daniel Bernoulli which we were considering ends with a discussion of the validity of the two principles by whose application the foregoing special problems have been solved. Bernoulli states that the "conservation of living forces" remains valid as long as there is no friction or other exterior resistance, but that the "proportionality of the velocity to the inverse of the amplitude," while only an approximation, is valid for most vessels, provided there is no motion suddenly created or destroyed. The latter statement is the

principle of incompressibility, expressed in an approximate form correct only for flow of incompressible substances in nearly straight pipes.

3. J. L. d'Alembert, *Essai d'une Nouvelle Theorie de la Résistance des Fluides,* Paris, 1752. Of this rare book only two copies, located at the Navy Department Library and at the Brown University Library, are known to be in the United States. The photostat on exhibit is loaned by the Naval Research Laboratory.

The circumstances of composition of this work are mentioned in the introductory section above. It contains the first publication of the equations governing irrotational flow of incompressible fluids in two dimensions. For axially-symmetric flow, these equations are stated in §45, the notations having been explained in §43. The equations for plane motion are given summarily in §73. The ideas and form of presentation are strongly influenced by the work of d'Alembert's lifelong rival, Clairaut, in his *Théorie de la Figure de la Terre, tirée des Principes de l'Hydrostatique,* Paris, 1743, where the principles of hydrostatics are similarly expressed. Like Clairaut, d'Alembert makes use of the principle of equivalent canals.

The *Essai,* despite the fact that it is so elaborate and so burdened with philosophy that very likely it has never been read in its entirety since 1755, is nevertheless a turning point both in physics and in mathematics. It contains the first field description of media in motion, a description which in other hands led quickly to partial differential equations and in particular to potential theory. It contains also what is generally described as d'Alembert's solution of the equation $\partial^2\phi/\partial x^2 + \partial^2\phi/\partial y^2 = 0$ in the form $\phi = f(x+iy)+g(x-iy)$, although in fact d'Alembert himself did not obtain the partial differential equation, deriving an equivalent result by manipulating differentials. The analysis is contained in §§57-60, which are famous for the first appearance of the "Cauchy-Riemann equations." The reasoning is essentially as follows: if

$$\frac{\partial p}{\partial z} = -\frac{\partial q}{\partial x}, \quad \frac{\partial p}{\partial x} = \frac{\partial q}{\partial z},$$

then $qdx + pdz$ and $pdx - qdz$ are complete differentials. By purely formal steps it is shown that $p + iq = f(x - iz)$, $p - iq = g(x + iz)$.

In §70 appears the famous "d'Alembert paradox." Put in modern terms, this "paradox" asserts that a submerged smooth body moving at uniform speed in a continuous irrotational flow of an ideal fluid at rest at infinity experiences no resultant force. It had been stated and proved more simply and more generally by Euler in 1745, and Oseen has traced it back to Spinoza. All the early statements refer to symmetrical bodies and employ some form of reversibility argument, whereby the pressure on the back side of a body is shown to cancel precisely the pressure at a corresponding point of the front side. However, no such special reasoning is required, and the result holds for smooth bodies of any form. It is essential, however, that the velocity field fall off sufficiently rapidly at infinity. For incompressible fluids, the necessary order condition is available from potential theory; for subsonic flow of compressible fluids it has been established rigorously only in recent months.

Since he is writing about a new theory of the *resistance* of fluids, and that theory turns out to give no resistance at all in the most natural situations, d'Alembert appears to be rather dismayed. He does not make a great

point of the matter, however, and passes on to treat of many other topics at great length but with few concrete results. Twelve years later he published the paradox again‡ in rather more sensational terms.

In the *Essai*, most of d'Alembert's dark suspicions regarding the theory are limited to the impossibility, rather than the uselessness, of the calculations. But time has shown that ideal hydrodynamics is far from useless. Even in the problem of resistance, d'Alembert turned out to be wrong. While he claimed to have shown that all motions are irrotational, three years later Euler proved (§5) that irrotational motion is only a very special case; and in rotational motion, the d'Alembert paradox no longer holds. Through proper development and exploitation of this idea, the modern theory of airplane lift has developed.

4. L. Euler, "Principia motus fluidorum" (1752-1755), *Acta Academiae Imperialis Scientiarum Petropolitensis*, 6 (1756-1757), 271-311 (1761). This paper contains Euler's first published treatment of the general problem of fluid motion. In 1752, shortly after the Berlin Academy's rejection of all pieces contesting for the prize on the resistance of fluids, Euler read before it a paper *De motu fluidorum in genere*, and Enestrŏm regarded this fact, which was ascertained by Jacobi, as sufficient evidence to date the present paper 1752. Another paper of Euler, itself dated 1755 (see §5), refers to this paper by its actual title.

The first part of the paper calculates in detail the change in volume of an infinitesimal tetrahedron carried by the motion through an infinitesimal time. Setting this change equal to zero yields a general equation expressing incompressibility. The calculation is carried out first in two dimensions, then in three. On page 286 is the conclusion of the three dimensional treatment, with the resulting *equation of continuity* in a notation still used at the present day:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0,$$

where u, v, w are the velocity components.

The second part of the paper introduces rather hastily the concept of fluid pressure and derives the dynamical equations for ideal fluids.

The work is dense with ideas waiting to be worked out. Among its contents we may observe the first occurrence of the secular determinant and its expansion, the introduction of the velocity potential and the acceleration potential, derivation of "Laplace's equation" for the former (cf. §3), construction of the general polynomial harmonic of degree n, derivation of "Helmholtz's vorticity equation" as a condition of integrability for the pressure field, derivation of "Killing's equation" for rigid motion, derivation of "Bernoulli's equation" for unsteady irrotational motions, a theory of fluid friction, derivation of the theory of flow in narrow tubes. It is interesting to notice that in this paper Euler concurs with d'Alembert's decision that all fluid motions possess a velocity-potential (irrotational flow).

5. L. Euler, "Principes généraux du mouvement des fluides," *Mémoires de l'Académie Royale des Sciences*, Berlin, 11 (1755), 274-315 (1757). This paper is the second of three parts of a treatise on the mechanics of fluids, published in consecutive pages in the same volume of the journal. In the first part Euler established the partial differential equations of hydrostatics and their general solution. In order to do so, he introduced the concept of *pressure* as a field acting upon an imaginary closed boundary and mechanically equivalent to the

‡ Suite des recherches sur le mouvement des fluides, *Opuscules mathématiques*, 5 (1768), no. 34, 132-170. See §I.

action of the fluid exterior to the boundary upon that interior to it. Previous authors had regarded the pressure as the weight of a unit column of fluid, or the height to which water would rise if the vessel were punctured. The distinction is extremely important, and it is Euler's concept of pressure which is used in modern hydrodynamics. Neither Clairaut's hydrostatics (1743) nor d'Alembert's hydrodynamics used the pressure at all, except possibly by implication. Their general principles consist in statements that certain differentials shall be exact. Euler was the first to conceive any branch of mathematical physics as a field theory governed by partial differential equations. Lagrange in comparing the work of d'Alembert and Euler wrote:

"But these equations did not yet possess all the generality and the simplicity of which they were susceptible. It is to Euler that we owe the first general formulae for the motion of fluids, founded on the laws of their equilibrium, and presented with the simple and luminous notation of partial differences. By this discovery, all the mechanics of fluids was reduced to a single point of analysis . . ." The importance of the pressure, even for hydrostatics alone, was put so highly by Todhunter that he wrote:

"Before Euler thus illustrated [*i.e.*, illuminated] the subject, there had been *demonstrations* in hydrostatics, but I cannot consider that these demonstrations were altogether intelligible."

The paper shown here clarifies and generalizes the pioneer work of 1752. Unlike the latter, it is smooth and pleasant reading, expressed in simple and easy notations. Both physically and mathematically it shows on every page what Fourier described as "that admirable clarity which is the principal character of all Euler's writings." The hydrodynamical equations are derived from what Euler called "the first axioms of mechanics," *viz.*, the indestructibility of matter and momentum.

On p. 286 Euler obtains his general dynamical equations for ideal fluids:

$$f_x - \frac{1}{\rho}\frac{\partial p}{\partial x} = \frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z}, \text{ etc.}$$

Previously he had derived the continuity equation for the compressible case:

$$\frac{\partial p}{\partial t} + \frac{\partial}{\partial x}(\rho u) + \frac{\partial}{\partial y}(\rho v) + \frac{\partial}{\partial z}(\rho w) = 0,$$

and he emphasizes the generality and the completeness of the set of four equations, complemented by a relation between pressure and density.

After a great many interesting tentatives and discoveries, Euler at the end of the paper concludes that mathematical analysis must be greatly improved before further progress in fluid dynamics can be made. "We see . . . how far distant we still are from a complete knowledge of the motion of fluids, and what I have just explained is only a feeble beginning. Nevertheless all that the theory of fluids includes is contained in the two equations presented above, so that it is not the principles of mechanics which we need for the pursuit of these researches, but analysis alone, which is not yet sufficiently cultivated for this end. One sees clearly what discoveries remain for us to make in this science before we can arrive at a more perfect theory of the motion of fluids."

6. L. Euler, "Recherches sur la propagation des ébranlemens dans une milieu élastique," *Mélanges de Turin*, 2^2 (1760-1761), 1-10 (1762; *Opera* (2)

10, 255-263; *Oeuvres de Lagrange* 14, 178-188. Throughout the latter part of his life Euler several times returned to the theory of fluids, either to extend its applications or to strengthen its foundations. His final work on the subject is a definitive Latin treatise in four lengthy instalments, published partly after his death.

The incorrect value for the speed of sound obtained by Newton in the *Principia* gave rise to a century and a half of controversy. It occurred to Euler that acoustics should be a branch of hydrodynamics, and that a proper value for the speed of sound should be obtainable from the hydrodynamical field equations. The problem had been taken up meanwhile by Lagrange, then an unknown young man at the beginning of his mathematical career. Lagrange had written to Euler on this subject as well as on the calculus of variations, and Euler replied with his usual generosity and candor.

This paper is the 1762 printing of one of Euler's letters to Lagrange, dated January 1, 1760. In it he derives a new set of hydrodynamical equations, expressed in terms of the positions of the fluid particles at some arbitrary initial instant. These initial positions are what are now called the "Lagrangian coordinates." The misnomer arose from the fact that Lagrange in the *Méchanique Analitique* did not quote the specific sources of any of his hydrodynamical material, permitting the reader to gain the impression that much of it appeared there for the first time, while in fact all of it is contained in earlier papers by Euler or by Lagrange himself.¶

Euler's second development of the field equations for fluids is in some ways more complete than the first, since it employs a more detailed kinematical description. All the principal equations, including the general formulae for inversion of partial differentiations, are given in the letter.

As is now easily understood, the proper speed of sound was not and could not be calculated from the hydrodynamical field equations alone. The result of Euler and Lagrange's researches was to establish the wave equation on a solid foundation, at the same time showing that the essence of the problem of the speed of sound lies in the form of the relation between pressure and density.

7. C.-L.-M.-H. Navier, "Mémoire sur les lois du mouvement des fluides" (1822), *Mémoires de l'Académie des Sciences de l'Institut de France,* (2) 6, 389-440, (1827). Euler's equations when applied to flow in a long straight pipe possess an infinite number of solutions; in fact, any continuously differentiable flow with straight parallel stream-lines is such a solution. However, a physical fluid when forced down

¶ Actually it is almost certain that Euler *began* his work on the general theory of fluids with the material description, but soon took up the simpler spatial description, which alone is used in his earliest publication. D'Alembert in the last section (§160) of the *Essai* refers sarcastically to "a manuscript theory on the current of rivers," which, he says, could not have fallen into his hands until August, 1750. He says further that "it would not even be impossible that the method presented in my work was unknown to the author of the memoir of which I speak, and did not help him in his researches on the current of rivers." Now there is a paper by Euler called *Recherches sur le mouvement de rivières,* which appears on pp. 101-118 of the Berlin Mémoires for 1760, not published until 1767. This paper presents internal evidence of being written before the *Principia motus* (1752); in particular, it employs a strange set of units used by Euler at this time, but abandoned in later papers; the formal structure is incomplete; and the specific flows considered as examples are trivial. According to Jacobi, a paper of this title was presented to the Berlin Academy on May 6, 1751. That it was *not* published sooner may be explained by the fact that in content it is a fragmentary and unsuccessful attempt, doubtless cast aside by Euler as he progressed in his researches. That it *was* published in 1767 may well be explained by Euler's angry departure from Berlin in 1766, depriving the academy of half its customary volume of MSS for publication.

If we can accept the date 1751 for this paper, we can set that year as the discovery of the material description. For it is this description alone which is employed in this paper.

such a pipe at sufficiently low speed assumes a single, perfectly definite velocity distribution. It follows that in Euler's equations some essential physical phenomenon has been neglected. In fact, Euhler's equations refer to fluids without dissipative mechanisms, sometimes called "perfect" or "ideal" fluids. While such fluids closely approximate the behavior of physical fluids in many circumstances, in cases where internal friction is important a more accurate mathematical model is required. For example, neglect of the adherence of fluids to solid boundaries is one of the reasons for the "d'Alembert paradox" (§3).

By the year 1820 the foregoing facts were becoming rather dimly apprehended. In 1821 Navier, a French engineer, constructed imaginary models both for solid bodies and for fluids by regarding them as nearly static assemblages of "molecules," mass-points obeying certain intermolecular force laws. Forces of cohesion were regarded as arising from summation of the multitudinous intermolecular actions. Such models were not new, having occurred in philosophical or qualitative speculations for millennia past. Navier's magnificent achievement was to put these notions into sufficiently concrete form that he could derive equations of motion from them.

On p. 414 occur the basic dynamical equations, now called "the Navier-Stokes equations," which govern the motion of incompressible viscous fluids. In modern vector notation these read:

$$\mathrm{f} - \frac{1}{\rho}\operatorname{grad} p - \frac{\mu}{\rho}\nabla^2 \mathrm{v} = \frac{\partial \mathrm{v}}{\partial t} + \mathrm{v}\operatorname{grad}\mathrm{v},$$

where v is the velocity vector and μ is the *shear viscosity*, a coefficient for which Navier gave an expression in terms of the intermolecular forces, but which is now usually regarded as an experimental function of temperature for each type of fluid. Navier's equation differs from Euler's in the presence of the term $(\mu/\rho)\nabla^2\mathrm{v}$, representing the effect of the internal friction, and, in so doing, raising the order of the differential equations from 1 to 2.

8. A. Cauchy, "Sur les équations qui experiment les conditions de l'élastique," ou les lois du mouvement intérieur d'un corps solide, élastique ou non élastique," *Exercises de Mathématique*, 3 (1828); *Oeuvres* (2) 8, 195-226. Fresnel's optical discoveries and the elastic theory of the ether which he proposed concurrently excited the intense interest of the entire scientific world. Immediately Cauchy took up the theoretical side of the subject, generalizing it profoundly and at the same time expressing the principles and results with the clarity and simplicity of the Eulerian tradition. The major results were announced in 1823, but proofs and explanations did not begin to appear until 1827, the second year of Cauchy's remarkable *Exercises*, annual volumes of short original papers by Cauchy alone, where jewels of number theory alternate with mechanics, complex function theory with algebra, pure geometry with the theory of infinite series.

Cauchy's first view regards matter as a continuous medium whose mechanical response is specified through *internal pressures*. These differ from Euler's hydrostatic pressure only in that their local resultant need not be normal to the surface element across which they act. This concept has the simplicity of genius. Its profound originality can be grasped only when one realizes that a whole century of brilliant geometers had treated very special elastic problems in very complicated and sometimes incorrect ways without ever hitting upon this basic idea, which immediately became the foundation of the mechanics of distributed matter.

Cauchy's main interest was in optical application, and he put great efforts into the elastic theory of light. §III of

this paper contains a by-product, mentioned briefly in passing. If a continuous body is "altogether devoid of elasticity," the stress tensor t_{ij} assumes the form (Cauchy's eq. (95) (97), written in indicial notation)

$$t_{ij} = \lambda v_{k,k}\delta_{ij} + \mu(v_{i,j} + v_{j,i}),$$

where v_i is the velocity vector. When these are put into Cauchy's general form of the momentum principle,

$$t_{ij,j} + f_i = \rho\left(\frac{\partial v_i}{\partial t} + v_{i,j}v_j\right),$$

there result dynamical equations which differ from those for viscous compressible fluids only in lacking the hydrostatic pressure term. Cauchy apparently regarded them as suitable for very soft solid bodies. If $\lambda = 0$, while μ is regarded as a suitable function of stress, rather than of temperature, they become the equations of plasticity proposed by St. Venant (1870), Levy (1870), and v. Mises (1913), but no such interpretation was intended by Cauchy, who stated that for homogeneous bodies μ is a constant.

9. S.-D. Poisson, "Mémoire sur les équations générales de l'équilibre et du mouvement des corps solides élastiques et des fluides" (1829), *Journal de l'Ecole Polytechnique*, 13 (cahier 20), 1-174 (1831). There is no doubt that Poisson first learned of the general equations of elasticity and fluid dynamics from the memoirs of Navier, which were read at the French Academy in 1821 and 1822. However, Poisson contended that despite the correctness of the final results, Navier's analysis was wholly faulty. The lives of both these savants were embittered by the senseless public controversy which followed: Navier repeatedly claimed priority, Poisson repeatedly denied it, on the ground that a result derived by false reasoning is not derived at all. It is interesting to note the change of fashions in physics: Poisson, who was a physicist, based his attack mainly on Navier's having replaced summations over the individual particles by integrations over volumes.

Neither critic nor criticized argued soundly. Both viewed a liquid as a nearly static assembly of Newtonian mass-points; they differed one from the other only in details which now seem unimportant, since such a picture of the liquid state has been entirely abandoned, and both derivations must be rejected. Their models are of interest only as examples of how a wholly wrong molecular theory can lead to wholly right gross conclusions—a fact often overlooked in physical circles today.

Although Poisson's part in this controversy was not admirable, his physical sagacity and analytical skill did not fail to get new results. Just as it was Navier, and Navier alone, who discovered the equations for viscous incompressible fluids, so it was Poisson, and Poisson alone, who discovered those for compressible viscous fluids. In modern notations, Poisson's stress formula is

$$t_{ij} = -p\delta_{ij} + \lambda v_{k,k}\delta_{ij} + \mu(v_{i,j} + v_{j,i}).$$

Here occur both the pressure p, as in Euler's and Navier's equations, and the two viscosities λ and μ, as in Cauchy's equations. While the generalization is quite straightforward from the continuum viewpoint, it must be remembered that Poisson labored with an intricate molecular model, which he endeavored to manipulate both with physical propriety and with mathematical exactness.

10. G. G. Stokes, "On the theories of the internal friction of fluids in motion,

and of the equilibrium and motion of elastic solides" (1845), *Transactions of the Cambridge Philosophical Society,* 8 (1844-1849), 287-319; *Papers* 1, 75-129. When Stokes wrote this paper, the general equations for elastic bodies and for viscous fluids had been in use in France for some twenty years, but they were not yet employed in England. It may be said that in England a result is not counted as known until an Englishman has rediscovered it. However, unlike some more recent compatriots, Stokes read, understood, and admired the continental literature, particularly the work of the great French mathematical physicists, whose methods he brought to a Cambridge stultified by traditional adherence to the faults rather than the virtues of Newton's methods. In this paper as in his other works Stokes did not disdain to add to the results of deep physical insight and high analytical skill the indications of thorough scholarship, and in particular he discussed in detail the work of Cauchy and Poisson on the same subjects.

Stokes's contribution, as far as the general equations are concerned, is an extraordinarily natural and incisive discussion of the concepts. In §2, we find a "Principle" which expresses the notion of internal friction in its most general form:

"That the difference between the pressure on a plane in a given direction passing through any point P of a fluid in motion and the pressure which would exist in all directions about P if the fluid in its neighborhood were in a state of relative equilibrium depends only on the relative motion of the fluid immediately about P; and that the relative motion due to any motion of rotation may be eliminated without affecting the differences of the pressures above mentioned." A hundred years later this same principle, expressed mathematically in tensor form, was shown by Reiner and Rivlin to lead to much more general equations of fluid dynamics and to predict extremely interesting new physical phenomena. Stokes himself, content with a linear approximation, derived the same equations as had Poisson, but in so doing he put the theory on a sound and clear phenomenological basis. As far as the received theory of fluids with linear viscous response is concerned, this paper was final.

A part of Stokes's discussion concerns the "Stokes relation" $3\lambda + 2\mu = 0$ between the two viscosities. While put forward with reserve by Stokes, and later virtually retracted by him, unfortunately this specialization was universally accepted in the physical literature until very recently. Experimental results, however, show that it can be correct only for monatomic gases at most.

The remainder of the paper contains: a determination of the boundary condition for viscous fluids; solution of the problem of decay of free plane infinitesimal waves in viscous fluids, whence arose later the theory of ultrasonic absorption and dispersion; correction of Newton's erroneous solution of the problem of a cylinder rotating in a fluid (see §1); solution of the problem of flow in a straight pipe; a scholarly and penetrating discussion of the theorem of Lagrange in ideal hydrodynamics; development of elasticity theory; and a critique of the work of Poisson.

POSTSCRIPT

It would certainly be wrong to conclude that analysis of the principles fundamental to the hydrodynamical equations stopped in 1845. True, such is the impression which one gains often enough from current textbooks, some of which produce the Navier-Stokes equations as empirical results established by experiment. As we have seen, while *experience* is indeed the basis of hydrodynamics, *experiment* played no direct part in the development of the general equations. The mathematical analysis of Navier, Cauchy, Poisson, and Stokes makes it plain that their results are only *first approximations* to those which would follow from a more general theory. It was natural enough that the main effort in hydrodynamics since 1845 should be directed toward obtaining solutions of the equations of Euler or Navier-Stokes and in comparing these solutions with experimentally measured values. As a result of this vigorous and thorough exploitation, we now have a fair idea both of the mathematics of classical hydrodynamics and of the range of its physical validity. But from time to time there have been attempts at precision of the more general ideas standing in the shadows behind Stokes's Principle. During the past seven years this question, whose theory might be named *Non-linear viscosity*, has become an active and vigorous field of modern mechanics.§

§ A skeleton history is given in §18 of my paper cited above. A treatise on the state of the theory up to January, 1952, is given in Chapter V of my paper, The mechanical foundations of elasticity and fluid dynamics, *J. Rational Mech. Anal.* 1, 125-300 (1952); 2, 593-616 (1953).

THE GAS TURBINE AS A PRIME MOVER ON U. S. NAVAL SHIPS

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ABSTRACT

The Navy has made considerable progress on gas turbines for ships since 1938. Some of the engines developed for auxiliary and propulsion drive are described herein. The application of these engines as auxiliary or propulsion drive in several ships is discussed.

INTRODUCTION

Fifteen years ago, the United States Navy became interested in gas turbines as a new prime mover for ships. Two years later, in 1940, the Bureau of Ships placed its first order with Allis-Chalmers Manufacturing Company for a 3500 HP laboratory evaluation unit. Today our Navy has approximately two hundred gas turbines either in fleet operation or scheduled for early installation. In comparison with steam turbines (first installed in 1908 Scout Cruiser *Chester*) and Diesel engines (first installed in Submarine E-1, 1912), the application of the gas turbine engine has been extremely rapid.

The Navy Department's original interest in shipboard application of the gas turbine was based largely on the potentialities for high thermal efficiency. However, after 10 years of laboratory and some shipboard operation, the characteristics which have been demonstrated most successfully by the engine are its light weight, small size and reliability of starting. Current test experience leads us to believe that reliability will be one of the major advantages of this machine aboard ship, but this remains to be demonstrated completely.

The characteristics required of Naval shipboard machinery have been covered in detail by others,[1] but briefly the major requirements are:

a. maximum reliability.

b. maximum economy of operation and maintenance.

c. minimum weight and space.

The relative importance of these requirements depends solely on the service installation selected. In its present gas turbine program, the Navy has capitalized largely on the superiority of this engine in meeting the minimum size requirements. Fuel economy has been a secondary consideration.

A major disadvantage of the gas turbine engine for shipboard application is its huge air consumption and sensitivity to ducting pressure losses. Current installations have been compromised in accessibility and performance to some degree because of the tremendous inlet and exhaust ducts required. Engines deep within the ship have suffered considerably in performance while those in small craft have filled the limited volume available with "tin" work. Exhaust disposal has been a problem due to the high temperatures as well as quantity of the gas. However, some use of the energy in the exhaust has been utilized for ventilating machinery spaces.

Subjects closely allied with gas turbine engine development are being pursued actively by the Bureau of Ships. Liquid cooling, rotary regenerators and air heaters are but a few sponsored directly by the Bureau. In cooperation with other members of the Defense Department, the Navy is actively engaged in critical material reduction, component improvement and residual fuel combustion problems.

We will discuss in the following paragraphs performance or design characteristics of some of the engines currently operating aboard ship as well as some of those now under development. Further, some of the major features of this application in ships will be discussed.

PRESENT ENGINES

The two main classes into which Naval gas turbine engines fall are propulsion and auxiliary drives. The Navy has three gas turbine engines which are developed and available for propulsive service. The first, the Boeing 502-2 (160 HP), is similar to other engines of the 502 series in that it consists of a single stage centrifugal compressor of 3/1 nominal pressure ratio when rotating at 36,500 rpm; a two stage axial flow turbine, the first stage of which is coupled to and driving the compressor. The second turbine stage is physically disconnected from the first stage and, except for air mass flow, is independent of the first stage. The second stage turbine rotates at a normal speed of 23,725 rpm. Fig. 1 shows an outline of the 502 engine and Table 1 lists its overall characteristics. An interesting feature of a split wheel turbine (where the driving member speed is independent of the compressor speed) is that an automatic torque build-up of approximately 2/1 is available under starting conditions. Also, with the split wheel, starting power is materially re-

TABLE 1

BOEING 502-2 GAS TURBINE

Description: Simple cycle gas turbine with an independent power turbine

SHP	160
Weight	220#
Specific Fuel Consumption (at full load)	1.3#/HP-HR
Dimensions	
Length	38.5"
Width	22.2"
Height	22.2"
Airflow	3.6#/sec.
Pressure Ratio	3.2:1
Turbine Inlet Temperature	1550°F
Output RPM	2750

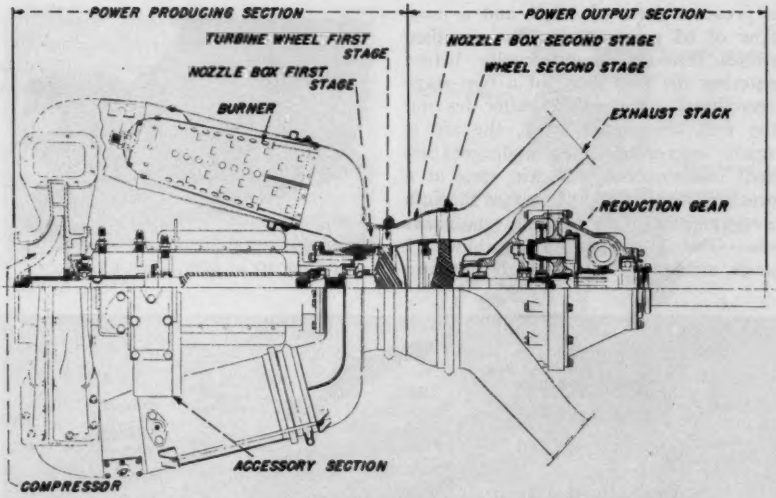

FIG. 1—Assembly and outline of Boeing Model 502 Gas Turbine Engine

duced since it is necessary to rotate only the compressor and its associated turbine in order to ensure a successful start.

The other two propulsion engines, the Metropolitan-Vickers G-2 and the Rolls-Royce RM-60 have been purchased from the British and plans are being drawn up for their installation in a Motor Torpedo Boat and a Destroyer Escort, respectively.

The G-2 has the following characteristics. The compressor is an eleven stage axial flow machine rotating at 8000 rpm and produces a pressure ratio of 3.68/1 at an air mass flow of 58.1#/sec. The compressor is driven by a single stage axial turbine. The power turbine, a three stage axial unit, is independent of the compressor turbine as in the case of the Boeing 502 above. The horsepower output at a turbine inlet temperature of 1436°F is approximately 4000. Fig. 2 shows an outline of the plant and Table (2) lists its characteristics.

TABLE 2

METRO VICK G-2 GAS TURBINE ENGINE

Description: Simple cycle gas turbine with independent power turbine

SHP	4000
Weight	9700# (includes gear)
Full load Specific Fuel Consumption	.86
Dimensions	
Length	17'7"
Width	5'0"
Height	5'4"
Airflow	58.1#/sec.
Pressure Ratio	3.68:1
Turbine Inlet Temperature	1436°F
Output RPM	1100

The RM-60 is somewhat more complex in arrangement than the other plants mentioned herein. Fig. 3 shows a schematic layout of the plant. The low pressure air compressor (eleven stage axial), driven at 7500 rpm by a L.P. two stage axial turbine, provides

a pressure ratio of 4.3/1 and a mass flow of 63 pounds/sec. The air then passes through an intercooler before entering the first stage of a two stage centrifugal compressor. After leaving the first centrifugal stage, the air is again intercooled then undergoes its final compression. The air, now at a pressure ratio of 18.5/1, passes through a regenerator to the two can type burners. The high pressure turbine (1 stage axial) drives the high pressure

FIG. 2—Metropolitan-Vickers G-2.

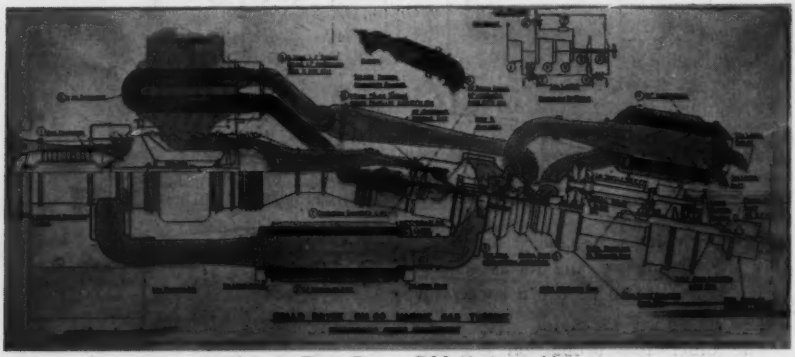

FIG. 3—Rolls-Royce RM-60 Assembly.

TABLE 3

ROLLS ROYCE RM60 GAS TURBINE

Description: Complex cycle gas turbine with an independent power turbine

SHP	5000
Weight	29,000#
Specific Fuel Consumption (at full load)	.67
Specific Fuel Consumption (at 60% full load)	.64
Dimensions	
Length	16'10"
Width	6'0"
Height	4'7"
Airflow	63#/sec.
Pressure Ratio	18.5:1
Turbine Inlet Temperature	1500°F
Output RPM	675

TABLE 4

SOLAR T-45 POWER PLANT OPERATING PERFORMANCE

Compressor inlet air temperature	81°F
Airflow	2.35 lb/sec.
Compressor pressure ratio	2.44
Compressor efficiency	74.5%
Combustion efficiency	95.0%
Turbine efficiency	78.0%
Turbine speed	39,800 rpm
Compressor discharge temperature	316°F
Turbine inlet temperature (average)	1142°F
Tallpipe temperature (without cooling)	900°F
Fuel flow	104 lb/hr
Specific fuel consumption	2.22 lb/hp-hr
Turbine shaft output	46.8 hp

compressor and the two stage axial I.P. turbine drives the output shaft. At an ambient temperature of 80°F, a regenerator bypass opens at approximately 4500 HP. This remains open through the power range to 5000 HP. Table 3 lists the characteristics of the RM-60.

The following engines were developed for use as auxiliary power (constant speed). They are listed in order of increasing power.

Solar T-45

The T-45 (50 HP) has several unique features. It is a hand started machine as used by the Navy. The rotating elements of this engine are extremely compact. A single stage centrifugal compressor impeller is mounted back-to-back with a single stage radial inward-flow turbine employing a thin plate between. The air enters the impeller from whence it discharges to a diffuser and an elbow type combustion chamber. Products of combustion pass through the turbine and exhaust axially through a short tailpipe. The rotating assembly operates at a speed of 40,300 rpm using anti-friction bearings lubricated by pressurized oil which is gravity scavenged back to the oil reservoir and sump. A cooling shroud fed by bled compressor air surrounds the turbine to keep the temperature of the turbine housing at a reasonable level. For pump operation a constant speed governor is provided along with an overspeed trip which unlatches a spring-operated fuel shut-off valve in the event of malfunction of the governor. The attached pump operates at 4500 rpm.

Fig. 4 shows the basic turbine and compressor arrangement and Table 4 is a table of performance characteristics.

Boeing 502-6

The 502-6 (160 HP) is virtually identical with the 502-2 described above except that it has been modified in

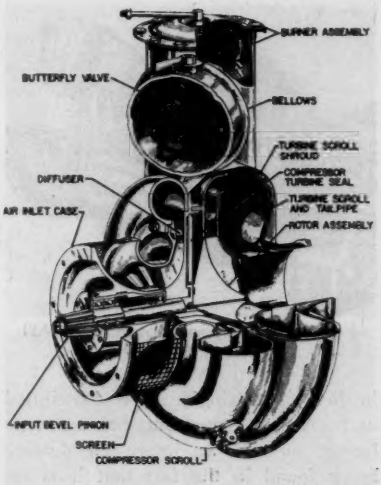

FIG. 4—Cutaway view of Solar T-45 Turbine Assembly.

minor respects to make it suitable for constant speed drive. The modifications consist of the inclusion of an interstage turbine bleed equipped with a hydraulically actuated waste gate which in turn is linked to an exhaust back pressure valve or damper. These devices have proved adequate in maintaining constant speed regardless of load and the speed of applying or removing load. In the case of removal of load for example, the waste gate is immediately opened and the damper brought to its closed position while the compressor is still rotating under full speed conditions. Since the gas stream is diverted from the power turbine, the normal tendency for the second stage power turbine to overspeed is removed.

Solar T-400

The T-400 [2] was the first gas turbine engine to be installed on a combatant ship. This 300 HP engine differs from the Boeing-502 and the T-45 in that it utilizes an axial ten stage compressor

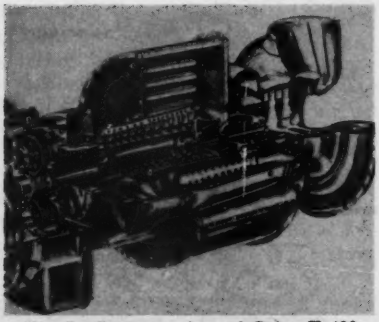

FIG. 5—Cutaway view of Solar T-400 Turbine Assembly.

in lieu of a single stage centrifugal unit. A single conventional can type burner is used, an interesting feature being found in the fact that it is reversed and located adjacent to the compressor. This was done in order to shorten the unit as much as practicable —length being the critical dimension aboard ship. A two stage power turbine drives the compressor at a rated speed of 20,000 rpm. Figure 5 shows a cutaway section of the T-400 while Table (5) gives a tabulation of performance.

Solar T-520

The T-520 is an outgrowth of the T-400. Design criteria are largely the same except that the air mass flow has been increased to 8 pounds per second and the horsepower boosted to 500 by the use of a three stage turbine. Figure 6 shows the T-520.

TABLE 5

SOLAR T-400 GAS TURBINE

Description: Single shaft simple cycle gas turbine

SHP	300
Weight	560#
Specific Fuel Consumption (at full load)	1.15
Dimensions	
Length	60"
Width	33"
Height	34"
Airflow	6.7 :#/sec.
Pressure Ratio	4.8:1
Turbine Inlet Temperature	1500°F
Output RPM	8000

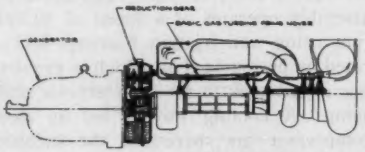

FIG. 6—Assembly T-520 Solar engine.

APPLICATION OF EXISTING PROPULSION ENGINES

In presenting the Bureau's program for the immediate application of the above gas turbine engines two main fields will be considered. These are propulsion and auxiliary power. Gas turbine engines that have been installed or are currently being purchased for installation as propulsion units include the following:

Boeing 502-2
Metropolitan-Vickers G-2
Rolls-Royce RM-60

Boeing 502-2

The Boeing 502-2 engine was installed in a 24' plane personnel boat. This installation, see Fig. 7 was made for the primary purpose of obtaining operating experience with a gas turbine in a boat. While the engine performed satisfactorily, this particular boat did not show the gas turbine engine as giving outstanding performance over the diesel initially installed.

FIG. 7—Plane personnel boat powered with Boeing 502-2, 160 HP Gas Turbine Engine.

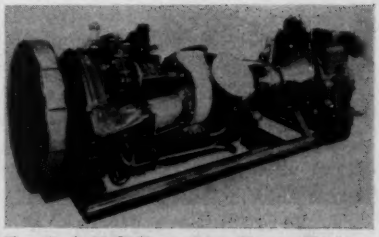

FIG. 8—LCVP Propulsion Power Package with Boeing 502-2 Gas Turbine Engine and a Snow Nabstedt Reverse Gear.

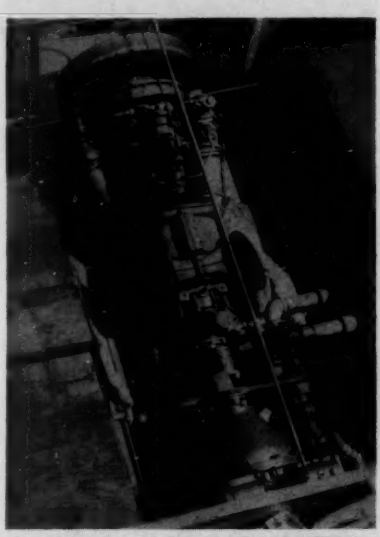

FIG. 9—Boeing 502-2 Gas Turbine Engine mounted as a propulsion unit in an LCVP.

An additional application of this engine was made in a standard LCVP. The engine and reverse-reduction gear were mounted as a complete power package on a tubular frame, see Fig. 8. The boat installation is shown in Fig. 9.

Extensive tests,[3] on this unit were made by the U. S. Naval Engineering Experiment Station, Annapolis, Maryland for the purpose of determining the suitability of this 160 HP gas turbine in the LCVP in lieu of the present diesel engine. The gas turbine engine was rated at 160 HP while the diesel engine had a rating of 225 HP. The gas turbine powered boat was obviously at a disadvantage under certain conditions such as beach retraction and speed. The primary purpose of this test was to determine feasibility of this engine for LCVP application. Included in the tests were the following:

Familiarization and check-out runs
Five hour endurance run
Speed runs
Maneuvering turns
Crash astern tests
Tow runs

The tests were conducted with varying amounts of ballast distributed to give the boat different trim. Since the propulsion plant weights varied from 3040 pounds for the diesel to 820 pounds for the gas turbine, the same trim could not be achieved with ballast in the same positions. The gas turbine and diesel powered LCVP's are shown in Figs. 10 and 11.

As a result of these tests, it is concluded that this gas turbine engine has a number of advantages over the diesel in the LCVP. These include:

FIG. 10—Gas Turbine powered LCVP.

FIG. 11—Diesel powered LCVP.

Easier starting
Simplicity of maintenance
Fewer moving parts
No warm-up period required
Simplification of cooling water system

Metropolitan-Vickers G-2

Utilization of the compact and lightweight features of the gas turbine has been attractive for driving high speed craft. The British have made an early start in this field by the installation of Metropolitan-Vickers engines in experimental craft.[4] The U. S. Navy is procuring two (2) Metropolitan-Vickers G-2 engines for installation.

It has been proposed that these engines be installed on the PT812, see Fig. 13. The general characteristics of this craft will be:

Full power, shaft horsepower	9600
Ship speed, knots, exceeds	40

One of several proposed studies shows a propulsion plant which consists of two gas turbines and two diesels. A gas turbine and a diesel would be coupled to each shaft through a vee-

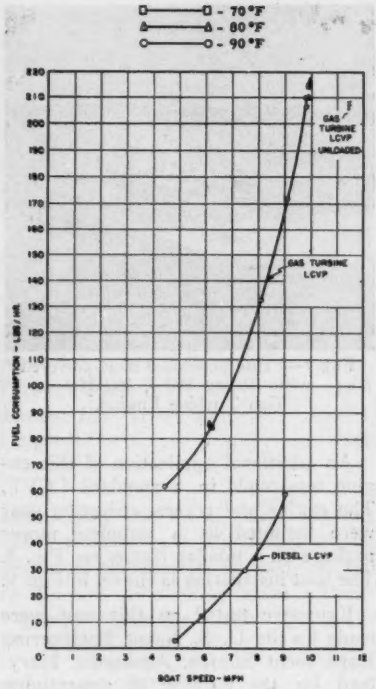

FIG. 12—Fuel consumption versus boat speed of Gas Turbine driven LCVP and diesel LCVP.

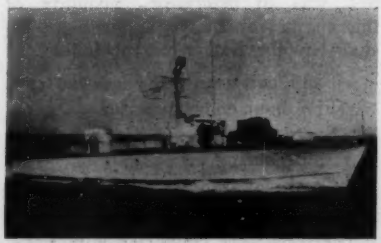

FIG. 13—PT boat 812. Two Metropolitan-Vickers G-2 Gas Turbine Engines are to be installed in a similar boat.

drive combining gear. A general arrangement of machinery is shown in Fig. 14. The diesel would drive through a two speed ahead, and one speed astern reverse-reduction gear to the main vee-drive combining gear. The diesel would drive through 2000/1100 rpm at continuous full power in conjunction with the gas turbine. It would drive through 2000/500 rpm reduction at cruising speeds.

The PT812 was selected for this proposed installation because of availability and also the requirements called for relatively high powers over comparatively short periods of time. A major advantage of this installation is the elimination of the hazards associated with use of gasoline as fuel. Full load can be maintained continuously with the gas turbine plant whereas full load on the gasoline plant is limited to short periods. The proposed gas turbine engines and diesel propulsion plants are scheduled for installation at the Philadelphia Naval Shipyard. It is expected that this conversion work will be started during 1953.

Rolls-Royce Gas Turbine RM-60

The operation of relatively large size gas turbines afloat is desirable in order to gain experience, train personnel and to realize the advantages offered by the light-weight plant.

The RM-60 engines are duplicates of those the British Admiralty plans to install in HMGB *Grey Goose*. The engines are to be installed by the Boston Naval Shipyard in a destroyer escort DE(FMR) twin screw type hull. The design includes two geared RM-60 engines that deliver 5000 SHP, each to controllable pitch 400 rpm propellers.

The general arrangement of machinery in the DE(FMR) conversion is shown in Fig. 15. This arrangement permits placing the gas turbines in line and utilizes the existing shaft lines of the ship.

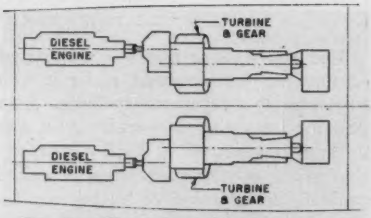

FIG. 14—Plan of machinery space on PT812 with a gas turbine and a diesel on each shaft.

Details of the engines have been discussed earlier in this paper. Astern power will be available from the controllable reversible propellers. Approximately 1000 HP will be supplied from each engine for astern power.

The installation of these engines will result in an approximate increase in power of 67 percent over the diesel power plant and at the same time decrease the plant weight by 15 percent. This ship will have a very marked increase in its top speed, about two knots. Cruising radius with the gas turbine driven vessel will be lower.

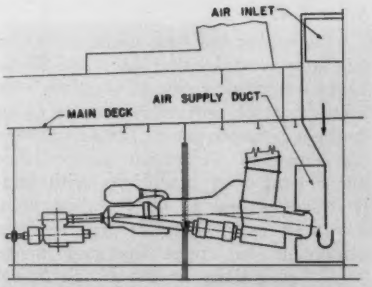

FIG. 15—DE(FMR) conversion to Rolls-Royce RM60 Gas Turbine Engine Drive.

APPLICATION OF EXISTING AUXILIARY ENGINES

The gas turbine offers a number of outstanding features that make it well suited for driving auxiliary units. As a unit for intermittent operation, the gas turbine is generally a highly competitive prime mover even when matched against the gasoline or diesel engine. For intermittent operation, over short periods of time, such as would be encountered in emergency generator sets or certain pumps, the relatively high specific fuel consumption is of little concern. The advantages of light-weight, dependability, and easy starting may more than offset the feature of high fuel consumption.

With the continuing demands to make more efficient use of available space and to pack more power into a given volume, investigations are continuing to find new applications for the gas turbine engine. Numerous uses such as drives for forced draft blowers, emergency generators, pumps, ship service generators and others have been or are under consideration.

The auxiliary power applications that are being developed by the Bureau of Ships for the gas turbine include the following engines:

Solar T-45
Boeing 502-6
Solar T-400 (completed)
Solar T-520

Solar T-45

This engine has been given extensive laboratory tests by the Bureau of Ships. Light-weight and ease of starting have been extremely attractive for use as an emergency water pump. Tests have been conducted to determine performance under controlled conditions with temperature as low as 60°F below zero. The unit as a piece of fire fighting equipment has been operated under "field" conditions by the U. S. Naval Fire Fighting School at the Philadelphia Naval Base. As a result of the work done at the Bureau of Ships' laboratories and at the Fire Fighter School, some further modifications appear desirable. At the present, a program is underway to develop a flexible exhaust hose that will permit operators to use the unit in a compartment and direct the exhaust gases to a location well removed from the operating area. This hose should be able to withstand exhaust temperatures up to 900°F continuous and 1200°F momentary. It should also be of such design as to permit collapsing for compact storage.

Seven of the pump units have been delivered to the Bureau of Ships. It is planned to have two of these evaluated by various Naval Fire Fighter Schools. Two may be utilized for investigating the possibilities of a unique application in removing ice from ships structures that operate in extreme cold. The exhaust from the turbine will be directed against ice coated structures and the pump discharge will be used to wash down slush resulting from the melting ice. The remaining units will be tested for other applications under shipboard conditions.

Boeing 502-6

Generators on the MSB5 Class, Fig. 17, are driven by the Boeing 502-6 engine. One of these generator sets is shown in Fig. 18. The Boeing 502-6 engine was selected for this application due to the stringent requirements for weight and size. Ventilation of the generator compartment presented a major problem which was solved by developing a stack eductor.[5] In this way, ventilating fans and motors were eliminated and a saving in electrical load and machinery weight was effected. Airborne noise from the compressor was reduced to an acceptable level by treating the air inlet chamber with a low density fibrous glass blanket. The exhaust noise was reduced by installing

FIG. 17—MSB-5 minesweeping boat equipped with Boeing 502-6 gas turbine engines to drive generators.

FIG. 18—Boeing 502-6 gas turbine engines mounted for generator drive.

a silencer, designed and tested by the U. S. Naval Engineering Experiment Station.

Operating experience on these units has not revealed any machinery difficulties other than those of a very minor nature.

Some consideration is being given to use of this engine for removal of ice from machinery and structures on vessels operating in extreme cold. It is planned to modify two engines by removing the power turbines and the output reduction gear and utilize the compressor and connected turbine as a heating unit. Exhaust gases from the set would be directed by flexible hose to iced-over areas. Work is now underway on this project and tests may be conducted during 1954.

Solar T-400

The first application of a gas turbine engine for an emergency electric generator drive was made by the U. S. Navy. The Solar T-400 was installed to drive a 250-KW generator set in the destroyer EDD828. The generator set

FIG. 19.—Solar T-400 gas turbine engine driving a 250 KW emergency generator.

FIG. 20—Solar T-520 engine on test.

is shown on test in Fig. 19. The engine is presently operating. Some difficulties in associated controls and starting equipment have been encountered.

Solar T-520

This engine is being produced for use as a drive for an auxiliary electric generator. The engine is shown in Fig. 20. The boat installation will feature a shroud over the engine and air will be drawn across the engine and into the stack by an eductor which utilizes the kinetic energy of the exhaust gases.[6]

ENGINES UNDER DEVELOPMENT

The Bureau of Ships recently developed a new concept with respect to gas turbine engines. Since it was recognized that there were needs for both constant and variable speeds, it seemed desirable from the point of view of spare parts supply to have the same engine type perform equally well in either category. This concept has been carried out in the development of the Solar T-522, a separate power turbine version of the T-520 mentioned above. All basic portions of the two engines are interchangeable. During manufacture, parts flowing through the shop are identical; only upon final assembly is the conversion from the constant speed T-520 to the variable speed split wheel T-522 carried out. The T-522 has, in the 500 horsepower range, the same functional advantages of torque multiplication and flexibility that the smaller Boeing 502 has. Fig. 21 shows a section of the T-522.

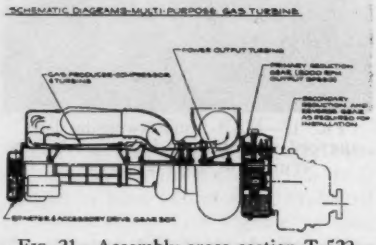
SCHEMATIC DIAGRAMS-MULTI-PURPOSE GAS TURBINE
POWER OUTPUT TURBINE
GAS PRODUCER COMPRESSOR TURBINE
PRIMARY REDUCTION GEAR, 13000 RPM OUTPUT SPEED
SECONDARY REDUCTION AND REVERSE GEAR AS REQUIRED FOR INSTALLATION

FIG. 21—Assembly cross section T-522 Solar engine.

Another gas turbine propulsion engine which the Navy has under development is the Allison 510-B1. This engine was originally conceived as a modification to the T-38 turbo-prop engine. By splitting the turbine between the second and third stages, it was found that the required performance and flexibility for marine application could be obtained. In its marine form, the engine consists of a twelve stage axial flow compressor rotating at a speed of 13,800 rpm, air through-put of 28.8 pounds/sec. and a pressure ratio of 6.41/1. The air leaving the compressor enters the combustion chambers at 533°F where the temperature is raised to 1500°F. The power turbine rotates at a nominal 7500 rpm developing 2000 horsepower (based on 80°F air to compressor). The exhaust gas temperature is about 890°F.

APPLICATION OF DEVELOPMENT ENGINES

Effective utilization of gas turbine engines that are now in various stages of development is being planned. Several end uses offer attractive possibilities for the engines now under development. Some of these are discussed briefly in the following paragraphs.

Solar T-522

One of the most attractive possible applications of this small gas turbine is in a propulsion plant for a 40 foot air rescue boat. The original design called for two 225 HP diesel engines for propulsion. An elevation of such an installation is shown in Fig. 22.

TABLE 6

WEIGHT STUDY

Description	Diesel	Turbine
Main Propulsion Unit	5300	1116
Gear Box	—	1100
Stack	—	250
Ducts and Shroud	—	188
Air Intake	—	46
Vents	—	54
Fuel Diesel 174 G		
Turbine 375 G	1210	2610
Fuel Tank	270	545
Muffler	270	—
Fresh Water Tanks	200	—
Fresh Water	334	—
Total	7584	5909
Difference 1675		

Weight study of Diesels and Solar T-522 Gas Turbine for propulsion of 40 foot Air Rescue Boat.

It is of interest to review some of the data compiled in the initial studies of this installation. In Table 6, the diesel engine weight is 5300 pounds while the gas turbine is 1116 pounds. Total weights, including sufficient fuel to give the gas turbine propelled boat the same cruising range as the diesel, of propulsion plants are 7584 and 5909 pounds for the diesel and gas turbine respectively. Thus, the gas turbine permits a weight saving of approximately 1675 pounds and maintains the same cruising range.

One of the most outstanding advantages of the gas turbine propelled boat is the high speed that can be realized. The maximum speeds are approximately 21 and 42 MPH for the diesel and the gas turbine boats respectively.

It is anticipated that this turbine installation will be completed and the boat tests started during 1954. There is no doubt but what some operational difficulties will arise during the course of this project, but it is believed that this particular application is one where the gas turbine will readily improve the boat performance in every respect.

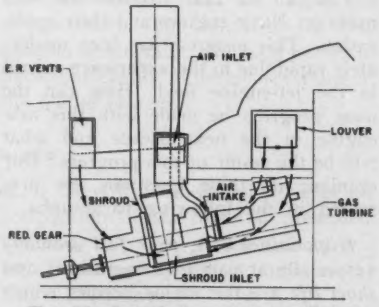

FIG. 22—Installation of Solar T-522 engines in 40 boat.

Allison 510-B-1

Consideration has been given to installation of this engine in several high speed boats. Advantages over the reciprocating engine include operation of continuous full power rating and

elimination of hazards due to the use of gasoline as a fuel. Studies have been made to determine suitability of this engine in a 52 foot air rescue boat. Several engine arrangements and combinations have been reviewed. They are:

(a) 2 shaft, 2 Packard W-14 gasoline engines

(b) 3 shaft, 2 Packard 300 HP diesels and 1 Allison 2000 HP gas turbine.

(c) 1 shaft, 1 Allison 2000 HP gas turbine.

The arrangement, (c), is shown in Fig. 23. This engine has possible application in the 70 foot retriever which is presently powered by two 700 horsepower diesels. The gas turbine would, in this boat, increase the power by some 40 percent, reduce engine weight by 80 percent and increase cruising range by 130 percent.

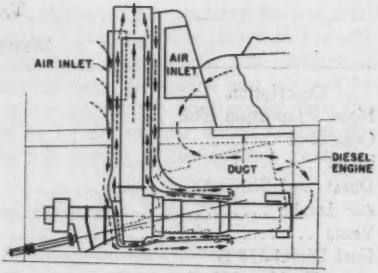

FIG. 23—Installation of Allison 510 B-1 engine for propulsion of 52' air rescue boat.

FUTURE TRENDS FOR NAVAL SHIPS

You can see that progress has been made on Navy engines and their application. This progress has been moderately rapid due to the experience gained in the jet-engine field. How can the most progress be made with this new engine in the next decade and what will be the result of this progress? Our opinions on these questions are presented in the following paragraphs.

High initial cost, poor fuel economy (especially at part load operation) and *short life* are the major hurdles which must be overcome before the gas turbine engine can be applied *generally* in Naval Ships. Marine diesel engines can be purchased for approximately one quarter to one tenth the price of a comparable gas turbine engine depending on the service desired. Fuel consumed by the gas turbine engine is two to three times as much as a diesel engine depending on the size selected. "Short life" is defined as, 500 hours at full power.

There is every reason to believe that the initial cost of engines will decrease rapidly under high production rates. However, in peacetime, the Navy has a limited production and shipbuilding will not contribute measurably to the reduction of cost through high production. Conversely, the Navy can contribute to lowering the fuel consumption and increasing the life of the gas turbine engine.

On the basis of developments in the gas turbine field within the past ten years and the demonstrated performance of present shipboard installations, we can anticipate continued exploitation of the gas turbine's small size during the next decade. These developments may be of sufficient magnitude to reduce the initial cost measurably. In our new ships we will see portable pumps, electric generators, and other emergency and standby equipment powered by gas turbines due to their small size, ease of starting and reliability. In the propulsion field, gas turbines will make great strides when applied to small high speed craft. These boats will be even faster with two to three times as much power in the same volume. Special applications will be found

also for these small machines. Compact units from 50 to 10,000 SHP will cover the range of simple cycle machines aboard ship with growing emphasis on the larger powers.

It is probable that a highly efficient complex cycle gas turbine engine for ship propulsion will be successfully developed within the next ten years. Such an engine within the 5000-15,000 HP range will have excellent part load efficiency and may incorporate some version of liquid cooling, regeneration and operate at 1600°F. This engine may or may not burn residual fuel but should be readily converted when practicable.

The next decade may possibly include the successful development of a compact gas heater. If so, closed cycle plants of 10,000-15,000 SHP suitable for large auxiliary vessels may be undertaken. The problem of residual fuel combustion will probably require use of selected fuels in the closed cycle plant despite claims to the contrary.

The most feasible gas turbine propulsion plant for large powers is the combined steam-gas turbine plant. The possibilities of this plant were outlined by Commanders Sawyer and Simpson in 1950.[7] This plant may be composed of conventional steam turbines supplying approximately 50% of the total power and one or more simple cycle light-weight gas turbines for peak load operation. This plant appears practicable for 20,000-50,000 HP. Similarly, a combined plant consisting of a diesel with booster gas turbines is also feasible.

Reverse-reduction gears and reversible pitch propellers suitable for reversing ships with gas turbine engines are under development and some are in operation. The reliability of this equipment for ships will soon be established sufficiently to permit reversing at the higher powers.

ACKNOWLEDGMENTS

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A DECADE OF PROGRESS IN SUBMARINE WATER PURIFICATION

FRANK E. CLARK

THE AUTHOR

graduated from Western Maryland College in 1935 with degrees in chemistry and education. Studied advanced physical chemistry for one year at University of Maryland and taught chemistry for four years before entering the Water Section at the EES Chemical Laboratory in March 1941. He became Head of the Water Section in 1942, Head of the Chemical and Physical Branch in 1946 and Head of the Process Branch in 1951. He was responsible for water quality, scale prevention and descaling studies on submarine stills as well as for ion-exchange purification of battery water and battery cooling water.

Prior to World War II, the cruising range of the American submarine was seriously limited by lack of equipment for making pure water from the sea. Hauling shore-water for the batteries and personnel reduced the space available for fuel and other critical items. The engine exhaust heat-exchangers (stills) used for producing emergency battery water were inefficient and subject to scaling problems. They would not produce sufficient water during battery charging periods, and their small production did not justify the fuel consumption, general wear and hazard of extra surface operation.

The dream of self-sufficiency in water production began to materialize in 1941 with the installation of production model, vapor compression stills on submarines. Spurred on by this achievement and the strategic importance of long range operations, progress in submarine water purification proceeded by leaps and bounds during the next decade. The modern submarine can produce not only a continuous, abundant supply of distillate, but a quality of water previously attainable only in the best of laboratories. Water is no longer a limiting factor in submarine cruising range. It actually is increasing range by extending battery life, and improving personnel morale. This outstanding progress in such a short span of years is a tribute to the cooperative efforts of industrial and military personnel which made it possible.

DEVELOPMENT OF THE VAPOR COMPRESSION STILL

Strange as it may seem, the vapor compression still which constituted the first milestone of progress, was not a new invention. The still operates on the principal of the heat pump, first described by Lord Kelvin in 1852. This involves compressing and expanding a vapor repeatedly, so as to use its latent heat of vaporization over and over again for heating or cooling. External power is required only to drive the compressor and make up losses from radiation and friction. The domestic refrigerator is a commonplace example of a heat engine operating in reverse.

In the case of the vapor compression still, the boiling process is started with electric immersion heaters in the main evaporator compartment. Vapor (steam) from the boiling water is compressed and passed back through tubes in the evaporator, where it condenses, while releasing its latent heat of vaporization in converting more sea-water to steam. In effect, the latent heat originally supplied by the electric heaters in boiling the first water is used over and over again. Heat is added by compression to make up sensible heat differences between the incoming sea-water and the out-going brine and distillate; to compensate for radiation losses in the still and friction losses in the compressor, and to account for slight differences in specific heats between the feedwater and the distillate. Since the quantity of heat required to evaporate a pound of water to steam (latent heat) is many times greater than that required to heat a pound of water from normal ocean temperature to the boiling point, the vapor compression still will produce from 10 to 15 times as much distillate as a single effect evaporator per unit of power or heat input. Some investigators have estimated that vapor compression stills of optimum size would be as effective as 15 stages of low pressure evaporation.

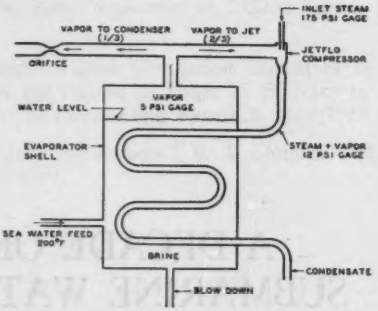

FIG. 1—Flow Diagram Regenerative Evaporator (1918).

The earliest known trial of a vapor compression still dates to about 1856. Jules Werbel of Switzerland obtained a U.S. Patent (236657) on a still with a reciprocating compressor in 1881. Addison Waterhouse, an American, also was granted a Patent (585943) in 1896. Neither made any practical use of his invention, presumably because of compressor difficulties. This was a major handicap in applying the vapor compression principal. Reciprocating compressors invariably contaminate the distillate with lubricants, whereas centrifugal and vane type compressors will not increase pressure and temperature automatically to compensate for lower heat transfer in case of scaling.

The U.S. Military entered the vapor compression field in 1917-1918 with tests of a "Regenerative Evaporating Apparatus" at the Naval Engineering Experiment Station in Annapolis. This device combined the principles of low pressure evaporation and vapor compression as shown in the flow diagram of Figure 1. The high pressure steam jet in Figure 2 compressed a part of the vapor from a conventional evaporator and forced it back through coils in the boiling brine. This process was reported to be as effective as three stages of low

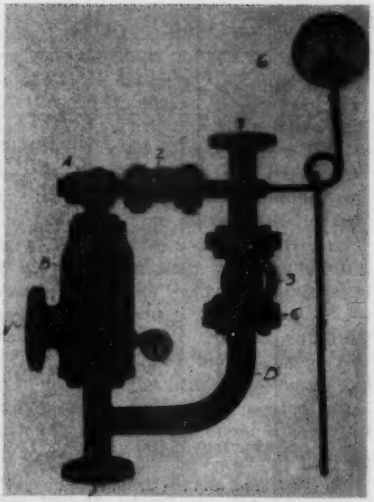

FIG. 2—Jet Compressor, Regenerative Evaporator.

A—Strainer;
B—Compressor Body;
C—Bypass Orifice;
D—Bypass Line;
E—Outlet to Evaporator Coil,
G—Pressure Gage;
S—Steam Inlet;
V—Vapor to Condenser.
2 and 3—Bypass Valves;

pressure evaporation and it avoided the problems of mechanical compressors. The still was never adopted for Naval vessels because it required an external source of high pressure steam. The submarine had no steam source and surface craft must evaporate with exhaust steam for best plant efficiency.

Despite the long history of vapor compression and the production of a few custom made, European plants between World Wars I and II, the U.S. submarine still was the first really significant application of compression distillation. It was developed from a laboratory still patented by Dr. Kleinschmidt of the Arthur D. Little Co., Boston in 1936. A 1000-gallon per day

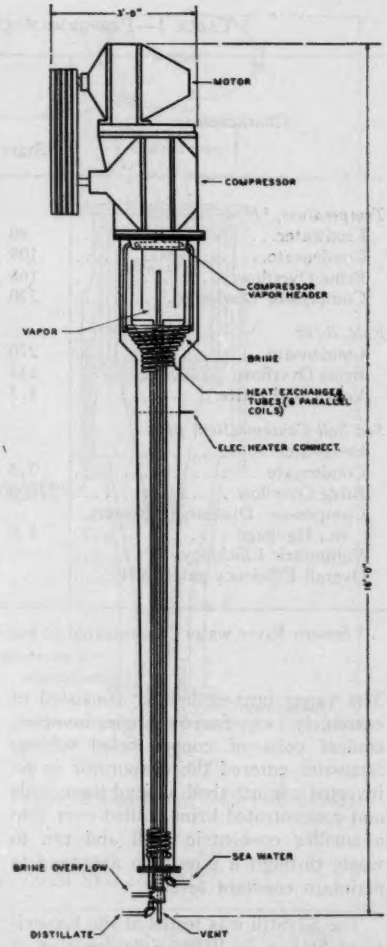

FIG. 3—Kleinschmidt S-1 Still (1938).

model of this still was made for the Bureau of Engineering (now the Bureau of Ships) in 1938, with the hope that it could be used on submarines. A schematic drawing of this still (Model S1) is shown in Figure 3. It used a Roots Connersville, two lobe, positive displacement compressor with close coupled, external timing gears.

TABLE 1—PERFORMANCE DATA, S-1 STILL (1939)

Characteristic	Operating Period, hours				
	Start	100	200	300	450
Temperature, °F					
Feedwater	90	—	99	—	96
Condensate	109		110		108
Brine Overflow	168	—	188	—	170
Compressor Discharge	320		377		400
Rate, lb/hr					
Condensate	270	260	242	234	208
Brine Overflow	144	—	155	—	130
Vent Condensate	1.5	—	—	—	—
Sea Salt Concentration, ppm					
Feedwater*	Approximately 35,000				
Condensate	3.5	—	5.0	—	3.5
Brine Overflow	120,000	120,000	140,000	150,000	140,000
Compressor Discharge Pressure, in., Hg. gage	8.0	—	19.0	—	41
Volumetric Efficiency, %	—	28.5	27.0	26.0	25.0
Overall Efficiency gal/KWH		3.5	2.5	2.0	3.0

* Severn River water concentrated to sea-water salinity.

The vapor heat-exchanger consisted of extremely long, narrow angle, inverted, conical coils of copper-nickel tubing. Seawater entered the evaporator in an inverted conical shell around these coils and concentrated brine spilled over into a smaller concentric shell and ran to waste through a pipe loop arranged to maintain constant level.

The S1 Still was tested at the Experiment Station in 1939 by evaporation of Severn River water. With a feedwater temperature of 90°F, the still produced up to 342 lbs. per hour of distillate at 109°F and 110 lbs. of brine over-flow at 168°F. In the beginning, the compressor operated at about 320°F discharge temperature and 8 in. hg. discharge pressure. As the test continued, compressor discharge pressure and temperature increased, and condensate production decreased rather sharply. Compressor discharge temperatures of more than 400°F were recorded. After 450 hours of operation, scaling was so severe in the vapor heat-exchanger, and evaporation efficiency was so low that tests were discontinued. The exchanger could not be dismantled or cleaned because of scale accumulations and eventually it was cut up with a torch for examination. A summary of the test data is given in Table 1.

These early tests showed that the S1 Still was impracticable for submarine use. The overall height of 15′ 5″ was incompatible with space restrictions, the operating periods were short, considering that relatively pure Severn River water was used in the trials, the unit was extremely difficult to dismantle and the compressor was inefficient and troubled with oil leakage from the timing gears.

On the basis of experience gained in testing the S1 Still, a new model 500 gpd, Kleinschmidt unit was constructed by the E. B. Badger Co. (Boston) and installed on Submarine S-20 for service trials. A sketch of this Still is shown in Figure 4. This second model resembled the S1 in basic design, but its overall height was only 5 feet. The compressor was the same type except that the external timing gears were separated from it by a longer shaft and double oil seals. The vapor heat-exchanger was radically different. It consisted of 6 inverted, wide-angle conical coils of ¼ in. copper-nickel tubing, connected to inlet and outlet headers by means of unions. The coils were separated from each other with sheet metal cones 0.02 in. thick. The separators were shorter than their respective cones so as to provide boiling spaces for the sea-water approximately 0.02 in. x 3½ in.

Submarine S-20 operated this still on sea-water and harbor water in the vicinity of New London, Connecticut during 1940 and 1941 and reported excellent results. The quality of the water obtained is shown in Table 2. On the basis of this service trial, 150 vapor compression stills of a very similar design were ordered from the Badger Co. for immediate installation on Fleet submarines. The first issue of this contract

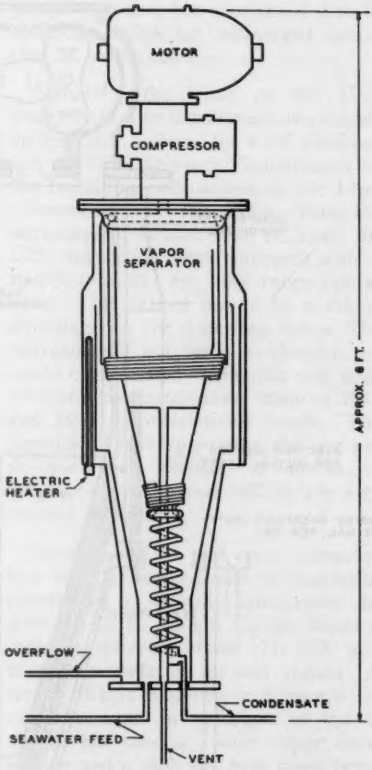

FIG. 4—Kleinschmidt S-20 Still (1940).

TABLE 2—WATER QUALITY S-20 STILL (1941)

Component	Result, ppm	
	S-20 Still	*Specification Max
Chloride, Cl^-	Less than 1	5
Iron, Fe^{++}	Less than 0.5	0.5
Nitrate, NO_3^-	Less than 5.0	10
Ammonia, NH_3	Less than 8.0	8.0
Total Solid (eight samples)	6.5 to 13.5	100

* Copper and nickel limits not included at this date.

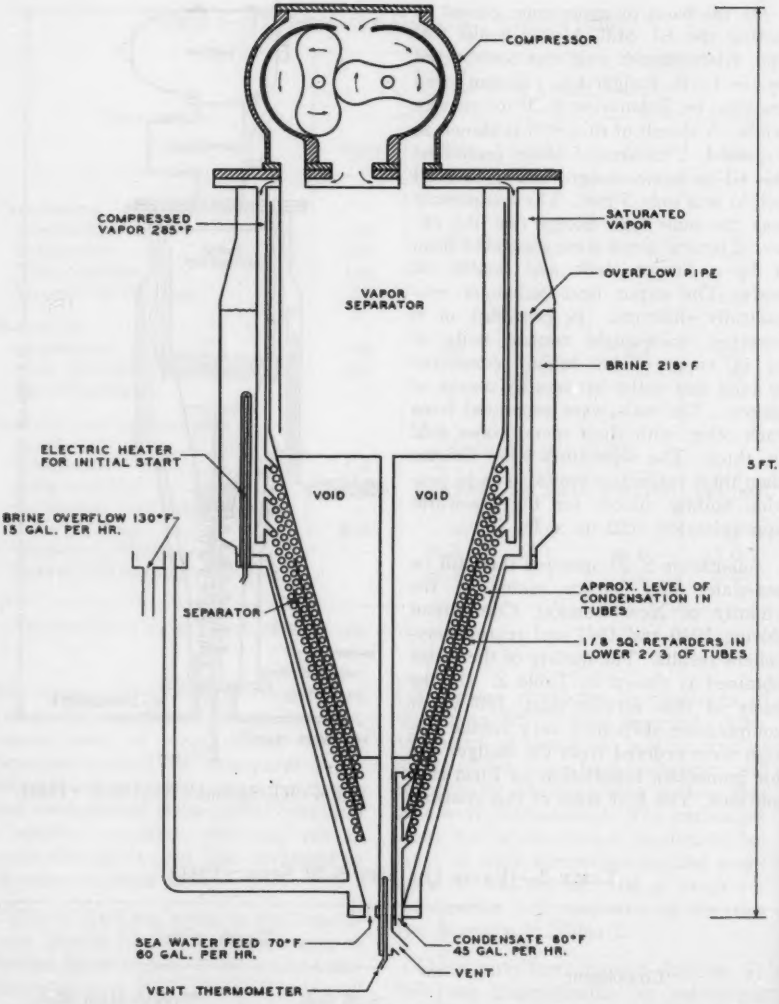

FIG. 5—Kleinschmidt Prototype S-Still (1941).

was received at the Station for type approval tests in March 1941. A sketch of the still in Figure 5 shows that it was practically identical with the S-20 model, except that its vapor heat-exchanger cones were shorter and still wider in angle. The rated capacity was 750 gpd.

It was a great disappointment to discover that the prototype would operate

only 40 to 60 hours on natural sea-water before it was heavily scaled. At the end of each trial, the concentric, vapor heat-exchangers coils were so completely embedded in compact magnesium hydroxide deposits that it was virtually impossible to clean them once the deposit had dried and hardened in place. Several more stills of the same contract were tested in rapid succession, with the same results. Station engineers suspected the problem to be the result of insufficient clearance between coils and consequent dry tube operation. This was confirmed by placing additional spacers between the coils. With two spacers, (0.044 in. separation) the operating period was increased to 200 hours. Over 400 hours of operation were obtained with 3 spacers and a separation of 0.066 in.

The pending emergency would not permit further experimentation. The remaining stills of the contract were altered to include 3 spacers per vapor cone and the first installation of the production model still was made on the USS *Snapper,* in Mare Island Naval Shipyard during July 1941. It was tested by Station engineers during a week of simulated patrol in the Pacific. An initial problem of insufficient feedwater pressure was eliminated through by-passing the gravity feedtanks and taking water directly through the feed pump. The still worked satisfactorily at the 25° roll encountered in the cruise, but it stopped several times because of sudden hull pressure changes. Positive changes increase the temperature required to boil the sea-water and therewith the amount of heat input and compressor discharge pressure required to operate the still. The problem was overcome by anticipating pressure changes (as in surfacing) and regulating the heat input accordingly. Heat balance data obtained during this cruise showed that an operating period of approximately 400 hours could be expected. The crew were very pleased with the new source of water, but considered it to be somewhat noisy for submerged operation in battle zones.

Following the trials on the USS *Snapper,* similar installations were made on the USS *Salmon,* the USS *Gudgeon* and the USS *Skipjack.* Installations on the remaining submarines of the Fleet followed in rapid succession. Thus, the beginning of World War II found the U.S. submarine fleet equipped with a source of water for long range operations. This turned out to be a major advantage for the American forces. The Germans did not begin to develop the vapor compression submarine still until 1942 and the installations made in 1942 and 1943 were relatively crude. The Japanese forces apparently did not get the word from Germany in time to use the vapor compression still to any significant extent.

Development of the vapor compression still did not end with its successful installation on existing submarines. In 1943 the E. B. Badger Co. developed a radically different Model X1, 1000 gpd unit for installation on new vessels. A sketch of this is shown in Figure 6. It was the same in principle as the S Model, but used a 3-lobe, vapor compressor and a shell and tube vapor heat-exchanger, instead of the troublesome, concentric conical coils. There also was an external shell and tube heat-exchanger to use waste heat from the distillate and brine overflow in preheating feedwater. The distillate sides of both heat-exchangers were tinned to reduce copper and nickel pick-up, another problem in the S Still.

Station trials of the X Model Still were made in the fall of 1943. As originally supplied, with the sea-water feed line entering the bottom of the shell (dotted line), the still operated for approximately 400 hours before excessive scale accumulated. The compressor discharge pressure increased from about 3 to 6 psi during this period. The scale

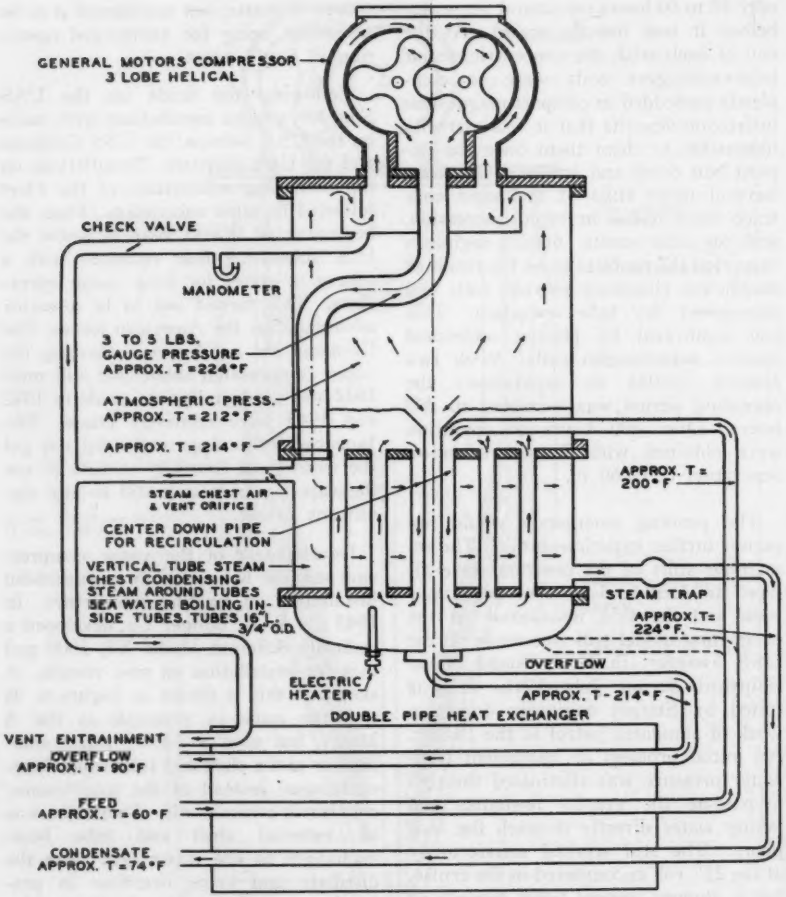

FIG. 6—Badger X-1 Still (1943).

was a salt-like incrustation with a superficial brown coloration. Analysis show it to be primarily magnesium hydroxide, with minor amounts of calcium carbonate and calcium sulfate.

On the supposition that sluggish circulation in the vapor heat-exchanger was contributing to scaling, the feedwater inlet was moved from the bottom to the side of the shell and the sea-water was introduced to the central downcomer, through a specially designed eductor-consisting of two ⅜" pipes and eight ⅛" diameter jets. This arrangement is shown by the solid line in Figure 6. It increased the heat transfer coefficient

TABLE 3—HEAT BALANCE DATA, X-1 STILL (1943)

Power	Temperature, °F	Rate, lb/hr	Enthalpy	Heat, Btu per Hour
Electric Heaters 231V x 24A x 3.414				18,927*
Compressor Motor 231V x 47A x 3.414 x 78% (efficiency)				28,880*
	Feedwater in, 43	1192	11.06	13,184*
	Steam in, 212	694	1151.7	799,280
	Condensate in, 225	694	193.1	134,011
	Overflow in, 214	498	182.0	90,636
* Total heat input (Heaters, Compressor, Feedwater)				60,991
Radiation Loss Liquid heat-exchange				6,306*
Radiation Loss Vapor heat-exchange (by difference)				11,267*
	Feedwater out, 192	1192	159.92	190,720
	Steam out, 228	694	1158.0	803,652
	Condensate out, 60	694	28.08	19,488*
	Overflow out, 80	498	48.05	23,929*
* Heat output (condensate, overflow, radiation)				60,991

Overall economy = 43.5 lb/KWH

of the evaporator from 510 to 620 btu/hr/sq ft/°F during a trial run. While time did not permit a test of its effects on scaling rate, the same change in 2000 gpd surface craft model extended operating time by as much as 40%. The heat balance data in Table 3 shows the general operating characteristics of this still and the excellent heat recovery provided by the external heat-exchanger.

The X Model Still provided an exceptionally pure distillate. When fed with sea-water, product quality was better than that of the S Model Still in respect to heavy metal contamination. When fed with sea-water distillate (double distillation), it was virtually impossible to detect impurities by the best laboratory test methods. Typical analyses are shown in Table 4.

While scaling occurred in the X Model and the operating period was not markedly longer than that of the S Still, the straight tube heat-exchangers were easily cleaned with conventional equipment. This model was built in large numbers for the expanded submarine program of World War II. Eventually, most of the surviving 750 gpd, S Models were replaced with the improved unit.

TABLE 4—WATER QUALITY X-1 STILL (1951)

Component or Property	Value		
	Single Distillation	Double Distillation	Specification Maximum
pH	6.3	6.45	no limit
Conductivity, micromhos	—	0.99	no limit
Chloride, Cl^-, ppm	1.0	0.05	5.0
Copper, Cu^{++}, ppm	Less than 0.05	0.035	2.5
Nickel, Ni^{++}, ppm	Less than 0.05	0.044	0.2
Iron, Fe^{+++}, ppm	Less than 0.01	0.001	0.5
Nitrate, NO_3^-, ppm	zero	zero	10
Ammonia, NH_3, ppm	zero	zero	8
Organic, ppm	zero	zero	50
Total Solid, ppm	2.0	0.38	100

The next major change in the submarine still consisted of attaching a vacuum pump to the condensate side of the vapor heat-exchanger so as to operate at a vapor pressure of about 4 psia rather than at atmospheric pressure. The electric heaters also were changed from the sea-water side to the condensate side of the heat-exchanger to prevent their scaling. A pilot model of this still was built by the E. B. Badger Co. for installation on the SS-563 Class submarine in 1949. Its flow diagram is shown as Figure 7. Tests at the Station with natural seawater showed that the vacuum still functioned satisfactorily and produced distillate equivalent to that of the X Still in both static and 45° roll operation. The boiling temperature of 150° yielded an extremely small amount of deposit in 500 hours of operation and suggested that the still would operate for at least 1000 hours before serious scaling. On the other hand, the coefficient of heat transfer for the vacuum still was about ½ that of the X Model Still. This resulted from the necessity of pumping more low pressure steam to obtain the same evaporation rate. For the same reason, the vacuum still was considerably larger and heavier than an X Model of the same capacity. These disadvantages outweighed the profits of reduced scaling, at least for submarines, where weight and space are at a special premium. Consequently there has been no general substitution of vacuum units for X Models to date.

The most recent type of vapor compression still developed for submarine use is the 300 gpd unit for the SSK, killer class, vessel. Sketches of two prototypes are shown in Figures 8 and 9. Figure 10 shows the former unit on the Station's test rocker. Except for its lower capacity and smaller size, this still is very similar to the popular X Model. The Still in Figure 9 is the same in principle but has a novel, carbon vane rotary compressor. These tiny stills were not intended to replace the X Model, but to meet the space restrictions and reduced water needs of the SSK Class.

A good device always is worthy of improvement, so development work continues on the vapor compression still. This is aimed primarily at the compres-

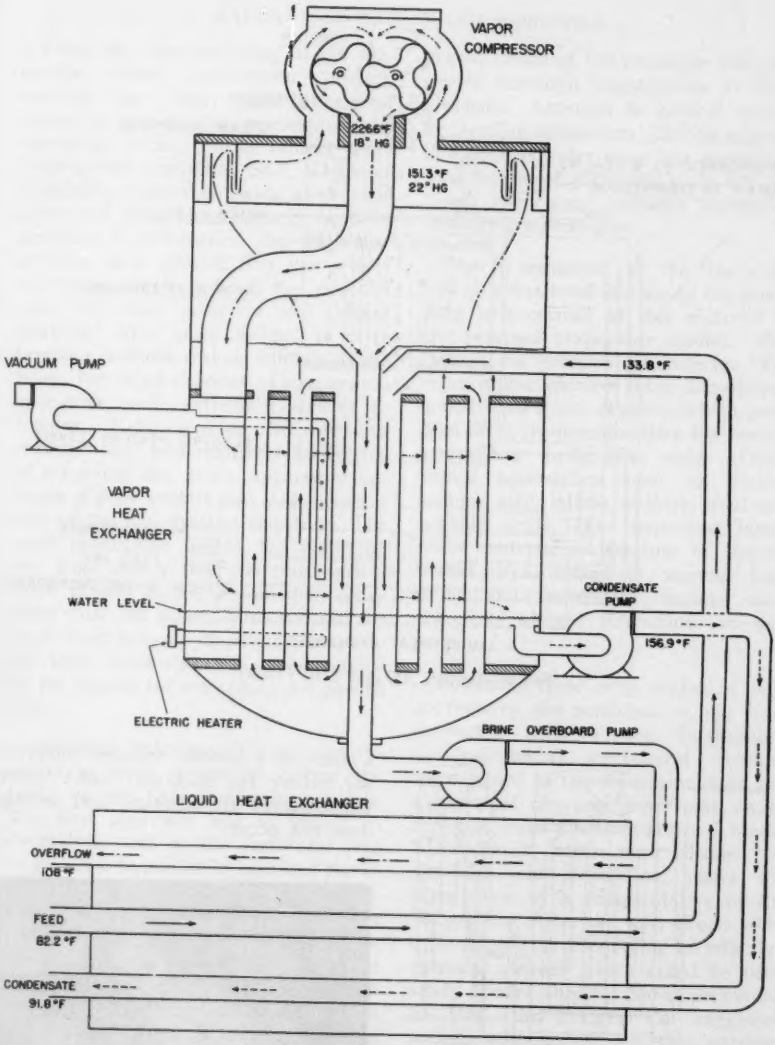

FIG. 7—Badger Vacuum Still (1949).

sor, which still is a relatively noisy and short-lived part of the unit. Multi-stage centrifugal compressors, liquid sealed pumps (Nash type) and even special reciprocating pumps are being studied. Improvements also may be possible in heat-exchanger design and circulation characteristics. Investigators dream of

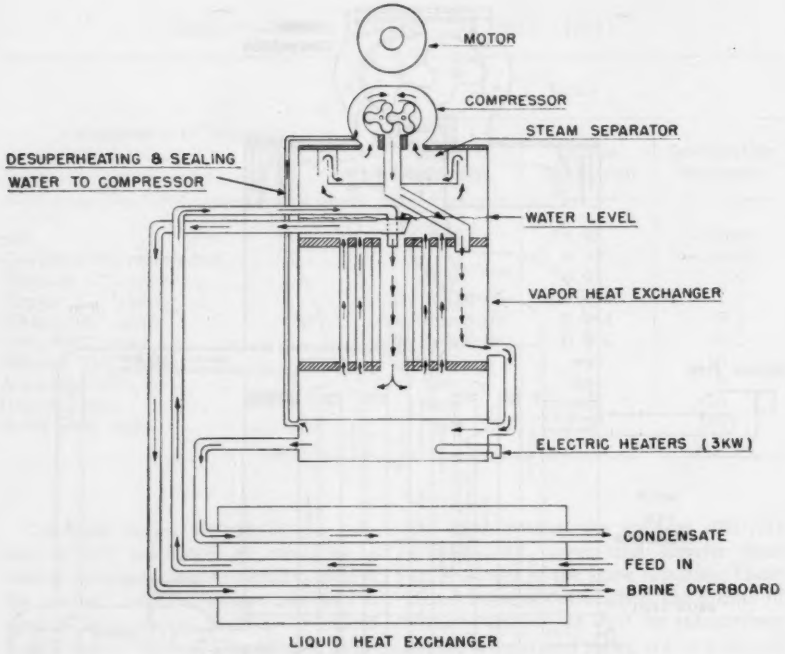

FIG. 8—Badger 300 gpd. Still (1949).

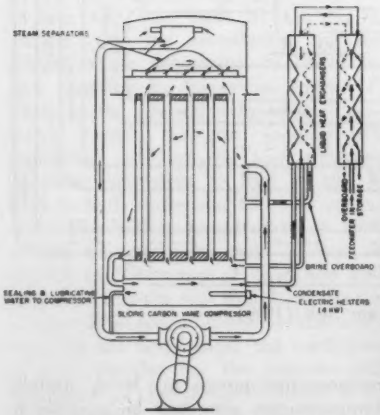

FIG. 9—Cleaver Brooks 300 gpd Still (1949).

a still with a durable, noiseless compressor, where the inlet and outlet water temperatures are identical and scaling does not occur.

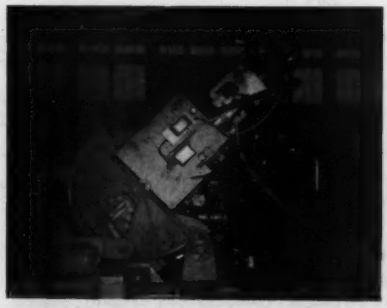

FIG. 10—Badger 300 gpd Still on Rocker.

MAINTENANCE OF DISTILLATE PRODUCTION

From the very beginning of the submarine water purification project, attempts have been made to extend operating periods by preventing and removing scale. These efforts were futile on the original S1 Still. The later S Models, with their wide angle tube cones and sheet metal separators, were amenable to mechanical cleaning. Experience soon showed that this was a relatively simple job if the deposits were kept wet prior to and during cleaning. Wet scale yielded to wire brushing without serious damage to the tubes, but dried deposits of magnesium hydroxide were extremely difficult to remove. Even soaking in cold 5% muriatic acid was relatively ineffective in removing dry scale, apparently because of poor contact and slow penetration of the fine grained structure. The most practicable means for removing dry scale was to heat the coils with a torch to 800 or 900°F and then spray them with cold water. This shocked the scale loose with no apparent damage to the tube metal and was recommended by the Station for emergency use aboard ship.

Attention was turned from scale removal to scale prevention during the trials of the first production models. The first approach was to install an electrolytic cell in the feedwater line to generate hypochloric acid and therewith to lower the pH and the magnesium hydroxide content of the boiling mixture. This cell consisted of a series of nickel anodes and cathodes separated by thin membranes and supplied with power by a motor-generator. It was arranged to discharge the acidic, anode fluid to feed-pump suction and the alkaline, cathode fluid to the brine overflow. This treatment was very successful in preventing scale during short exploratory runs. It was troubled with stray current problems, and the nickel electrodes disintegrated very rapidly. The urgent status of the prototype test prevented thorough investigation of these problems. Attempts to control acidity by bleeding ammonium chloride solution into the feedwater were less successful. This treatment prevented scale but ammonia carry-over seriously contaminated the distillate.

Starch treatment of the sea-water feed also was tried because of the promising performance of this material in low pressure evaporator studies. This showed no promise whatsoever. The vapor heat-exchanger tubes immediately fouled with sticky deposits which were even more troublesome than the normal magnesium hydroxide scale. Other logical approaches such as feeding sodium acid sulfate, sulfuric acid and organic acids, like citric and lactic, never materialized because of the inherent disadvantage of storing, handling and accurately feeding such chemicals aboard submarines in war time.

Following these early studies of scale preventives, the pendulum swung from prevention back to cure. Instructions for painstaking mechanical cleaning were issued to the submarine fleet and a chemical cleaning depot was established at Pearl Harbor. Here, S Model Kleinschmidt Stills were cleaned by muriatic acid circulation, under the supervision of a representative of the Badger Co. After the war, efforts were concentrated on discovering an effective chemical cleaner which could be used safely aboard ship by Naval personnel. In 1947, the Badger Co. suggested sodium acid sulfate for this purpose. This hydrolyzes to sulfuric acid which does not volatilize at still temperatures. The USS *Amberjack* (SS-522) made a one-year service trial of the Badger method and reported it to be successful. In 1948 and 1949 Station engineers made several service trials of similar

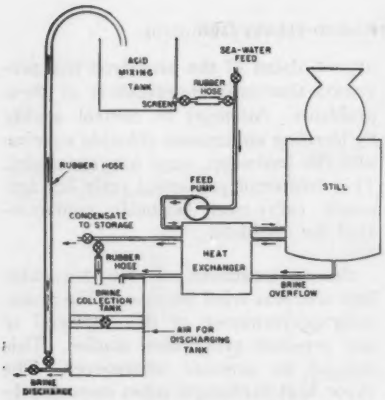

FIG. 11—Flow Sheet, Acid Sulfate Cleaning (1949).

acid sulfate descaling procedures on heavily scaled stills of the USS *Flying Fish* (SS-229), the USS *Raton* (SS-270) and the USS *Sable Fish* (SS-303). As a result of these trials, standard instructions for acid sulfate cleaning aboard ship were accepted for general Navy use in 1949. A flow sheet of the process is shown as Figure 11. The acid solution flows through the heat-exchangers to the still and the distillate and brine overflow are returned via the heat-exchanger to the brine collection tank. From here the mixture is blown back to the acid mixing tank with air. In case distillate or brine is lost during the cleaning, the volume is made up by bleeding sea-water into the system.

The only special equipment required for acid sulfate cleaning is a 25 to 35 gallon tank, several lengths of rubber hose and a few extra valves. A waste can or rag container can be used for the acid tank and returned to its regular duty between cleanings, so that storage space for chemical cleaning equipment is less than that for manual cleaning tools. From 25 to 40 pounds of sodium acid sulfate, a white salt, is required to clean a heavily scaled still. The cleaning can be done without stopping the still, by switching from the sea-water feed to the acid tank. It is even possible to use the distillate produced during the cleaning period, but this is not recommended except in cases of emergency. With cleaning complete, it is a simple matter to switch from acid circulation to sea-water feed and restore normal distillation. By carrying limited amounts of sodium acid sulfate aboard and cleaning the stills after every 250 to 450 hours of operation, it is possible for the modern submarine to produce pure water continuously unless mechanical failures occur.

Investigation of chemical cleaners did not end with adoption of the sodium acid sulfate method. A search was made for solvents, which would remove traces of calcium carbonate and calcium sulfate from the hotter parts of the heat-exchanger, as well as the principal component, magnesium hydroxide. Mare Island Naval Shipyard made service tests with citric acid, an excellent solvent for calcium carbonate. The Station made similar tests with this chemical, as well as with lactic acid, sodium gluconate, sodium versenate and various mixtures of these chemicals with each other and with sodium acid sulfate. To date these studies have not produced a better routine cleaner. Citric acid yields heavy sludges with magnesium and carries over if the compressor is operated during the cleaning. Lactic acid dissolves magnesium scales, but it is less effective on the troublesome calcium compounds. Mixtures of the two are somewhat better than either alone, but still are generally inferior to sodium acid sulfate. In the present stage of development it is more practicable to use citric acid as a secondary cleaner if stubborn calcium deposits develop during long period operation.

Following World War II, efforts were renewed to discover a scale preventive for vapor compression stills.

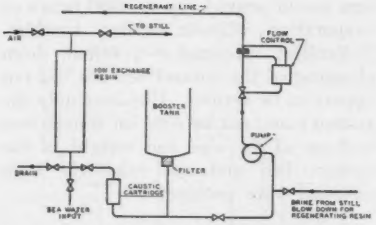

FIG. 12—Flow Sheet for Ionics Descaler (1949).

The Bureau of Ships contracted with Ionic Inc., Boston, for investigation of ion-exchanger pretreatment of the seawater. A system was devised whereby calcium and magnesium were removed with cation-exchange resin and the spent resin was regenerated with soft concentrated brine from the blowdown of the still. The brine yielded approximately 80% regeneration of the resin on the first cycle, but capacity declined with every cycle and became practically zero after 6 or 7 cycles. Maintenance of capacity required the addition of 30 pounds of caustic-soda ash mixture of the brine for every day of operation. The flow diagram in Figure 12 shows that the system had additional disadvantage of excessive size and weight.

During this same period (1948-1950) the Corp of Engineers supported a similar contract with the University of California for development of scale preventives. This yielded a contact

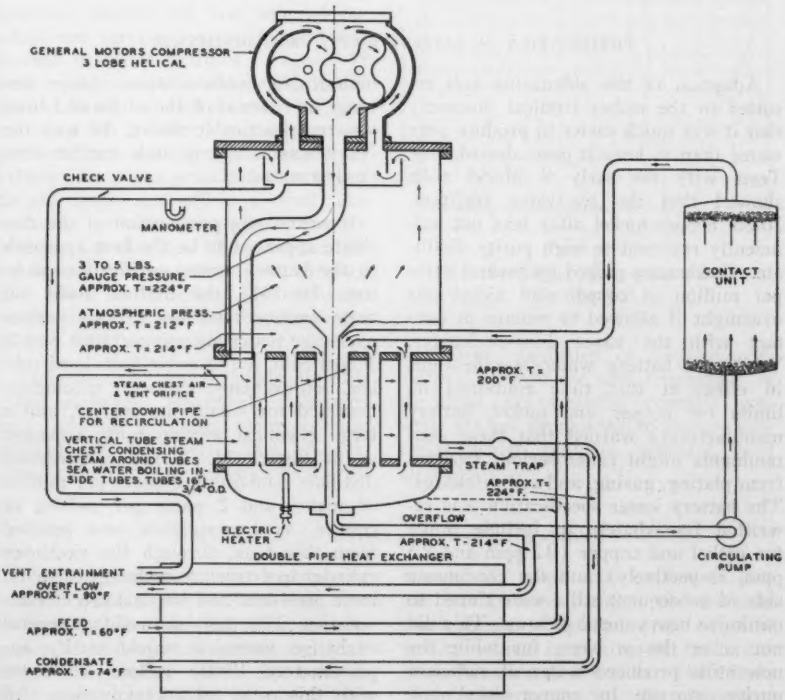

FIG. 13—Flow Sheet of Contact Stabilization Unit (1950).

stabilization treatment which was more promising than the ion-exchange approach. A flow diagram of this system is shown as Figure 13. Briefly the process consisted of circulating boiling sea-water from the still through an external contact bed of sand, limestone chips or glass wool and returning it to the evaporator, at a flow rate approximately 5 times that of the make-up sea-water rate. This had the same effect as feeding 5 or 6 times the quantity of sea-water without changing the distillation rate. It reduced contact times and concentration effects in the still and provided an external seeding bed for deposition of magnesium hydroxide and other scale forming crystals. Service trials on advance base type vapor compression stills showed that this system would provide up to 5000 hours of evaporation without scaling troubles. Difficulties eventually resulted from clogging of the contact bed but did not appear to be serious. Unfortunately the system could not be used on submarines because of the size and weight of the contact bed and the relatively high pumping rate required.

The thorough investigation of scale prevention included a number of proprietary devices reported to prevent evaporator scales. These trials were made on an X type, submarine, vapor compression still fed with natural sea-water. In no case was scale formation significantly different from that obtained with no treatment of the feed-water.

PURIFICATION OF BATTERY WATER FROM DISTILLATE

Adoption of the submarine still resulted in the rather ironical discovery that it was much easier to produce pure water than to keep it pure aboard ship. Tests with the early S Model stills showed that the sea-water resistant, 70-30, copper-nickel alloy was not sufficiently resistant to high purity distillate. Condensate picked up several parts per million of copper and nickel-ions overnight if allowed to remain in contact with the vapor heat-exchanger. While the battery water specifications in effect at that time contained no limits for copper and nickel, battery manufacturers warned that these contaminants might cause serious troubles from plating, gasing, and self-discharge. The battery water specification was rewritten immediately to include limits for nickel and copper (0.2 ppm and 2.5 ppm, respectively) and the condensate side of subsequent stills were tinned to minimize heavy metal pick-up. This did not solve the problem, for while the new stills produced water of sufficient purity, storage in copper-nickel and monel ships' tanks resulted in the same undesirable contamination. Since tinning, or renewal of the tanks and lines was not practicable during the war, the Navy was forced to seek another corrective measure.

Ion-exchange purification of the distillate appeared to be the best approach to the battery water purification problem. In 1943, the Station made full scale service tests on various cation-exchange materials using a 1000 gpd X Model Still, a 1/3 cubic foot, hard rubber, ion-exchange cylinder, specifically designed for submarine service, and a large chemical mixing tank, arranged as in Figure 14. Vapor compression distillate containing 3 parts per million of nickel and 2 parts per million of copper, as the sulfates, was pumped from this tank, through the exchange cylinder to determine exchange capacity, back pressures and ion leakage characteristics. The study showed that several exchange materials would purify approximately 10,000 gallons of water with this order of contamination. All yielded essentially zero metal leakage

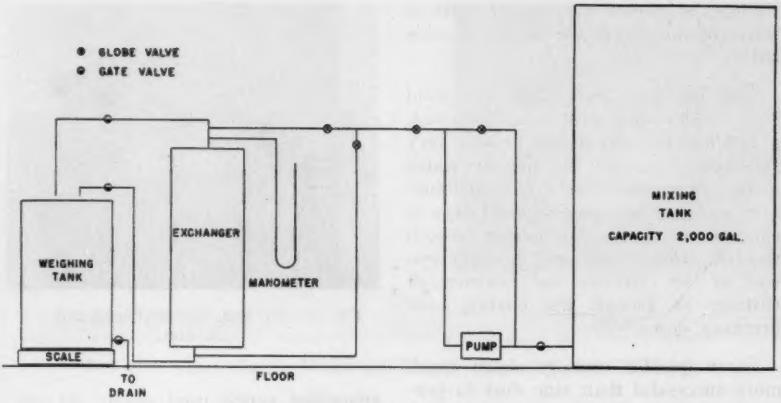

FIG. 14—Flow Sheet of Ion Exchange Test.

until exhaustion of the bed. A resinous material, Duolite C3, was selected for submarine service because it combined several desirable features. Figure 15 shows the absorption characteristics of this material for nickel-ion. The performance in respect to copper was similar. Ion-exchange purification of battery water was practiced throughout the emergency and still is in effect. The exchange cylinder generally is located between the distillate tank and the filling hose so that water is drawn through it in filling the batteries. The exchange cylinders are renewed at regular intervals to avoid exhaustion.

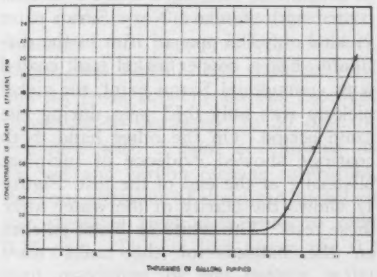

FIG. 15—Nickel Absorption Curve Duolite C-3.

In removing heavy metals by this cation-exchange treatment, hydrogen ions from the exchange resin are substituted for the metal ions. Consequently the distillate becomes acid with equivalent quantities of hydrochloric, sulfuric or carbonic acid, depending on the metal salts originally present. These acids are not detrimental to storage batteries which contain sulfuric acid already.

PREVENTION OF DISTILLATE CONTAMINATION

The inconsistency of repurifying water which should have been kept pure in the first place touched off an investigation of resistant tank metals and coatings. The Station made the tests in scale model tanks using a special tank rocker to simulate the roll of a submarine. In some tests carbon dioxide gas was bubbled through the distillate continuously to determine the effect of acidity which might result from improper venting of the stills. The effects of the maximum permissible concentration of sea salt also was determined.

Figure 16 shows the rocker with a series of tanks and the carbon dioxide bubbler.

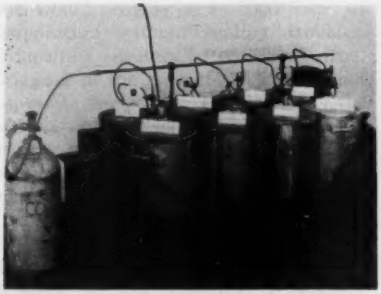

FIG. 16—Rocker, Water Tanks and Co_2 Bubbler.

The first tests were made with mild steel tanks coated with zinc dust paint, a combination which had yielded very satisfactory service for potable water storage in surface vessels. This combination was very acceptable for 30 days of continuous storage, but longer periods showed gradual increase in zinc content of the distillate and evidence of rusting, as though the coating was breaking down.

Saran plastic coatings were much more successful than zinc dust in preventing corrosion of steel and nonferrous tank metals. During 7 months of continuous rocking, a black iron tank coated with standard Navy Saran paint yielded only 0.3 ppm of iron in the distillate. For a copper-nickel tank coated with commercial Saran paint, the nickel pick-up was only 0.13 ppm during the same period. On the other hand, both coatings showed evidence of incipient blistering at the end of the test. Figure 17 shows the clarity of the water after these tests. The white or black patches on the bottoms of the tanks were enamelled panels used simply for contrast in making the photographs. It was concluded that these coatings could be used for prevention of battery water contamination during storage, provided reapplication at 6 month or 1 year intervals would be practicable. Actually this would be more troublesome and costly than use of ion-exchangers.

The survey of resistant tank metals showed that all nickel alloys, with the exception of 18-8 stainless steel, released nickel to high purity distillate at a relatively rapid rate. This is par-

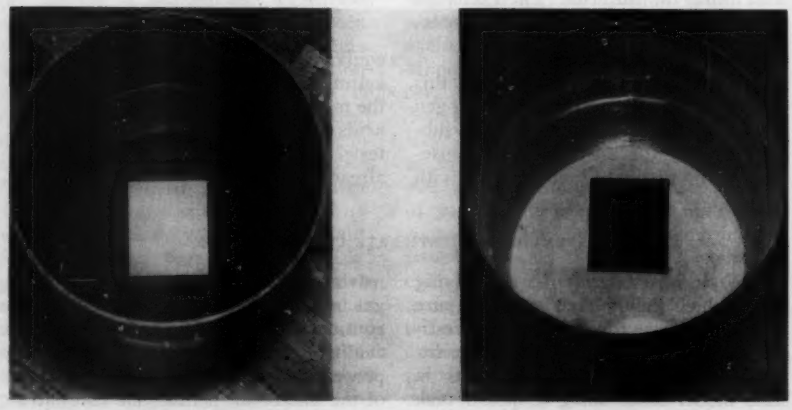

FIG. 17—Water Clarity, Saran Painted Tanks (30 Days).

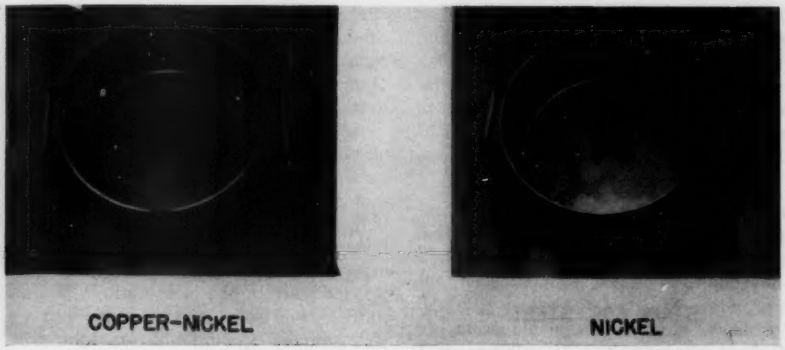

FIG. 18—Water Clarity, Nickel and Copper—Nickel Tanks (30 Days).

ticularly true when carbon dioxide is present. Distillate rocked for 30 days in 70-30 copper-nickel tanks accumulated 0.87 ppm of copper and 2.0 ppm of nickel. When contaminated with 5 ppm of chloride ion as sea-salt (battery water limit) it absorbed 0.3 and 2.3 ppm of copper and nickel, respectively. Bubbling carbon dioxide through the distillate in addition to the sea-salt increased the copper and nickel concentrations to 4.8 and 27.6 ppm. Generally speaking, both inconel and monel were more resistant than copper-nickel to vapor compression distillate without carbon dioxide. Inconel also was somewhat better in the presence of carbon dioxide, however, the concentration of nickel picked up by the distillate (1.76 ppm) greatly exceeded the specification limit. Monel was heavily attacked by carbon dioxide saturated water, which dissolved 173 ppm of nickel from the alloy in 30 days. This was more than the pick-up from a pure nickel tank (89 ppm). In all cases the rate of metal solution appeared to be uniform over the 30-day period. Figure 18 shows the effects of this heavy metal solution on the clarity of water in copper-nickel and nickel tanks. Turbidity was so great in the latter that the black, contrast panel was scarcely visible.

In contrast to the relatively poor performance of copper-nickel, inconel, monel, and nickel, 18-8 stainless steel and tin (over copper) showed excellent resistance to distillate. In 30 days of exposure with 5 ppm of chloride as sea-salt and carbon dioxide saturation, the concentration of dissolved nickel in the stainless steel tank rose to only 0.23 ppm. This is just above the 0.2 ppm maximum of the battery water specification. The solution of chromium and iron was essentially zero. There was no evidence of copper or tin solution in the case of the tinned copper tank. Further tests with a columbium stabilized, low carbon, 18-8 stainless steel tank resulted in solution of 0.1 ppm iron and 0.08 ppm nickel during 166 days of continuous rocking with sea-salt and carbon dioxide contamination. Tests with other stainless steel tanks showed some variation in iron solution, apparently because of improper passivation of the surfaces or iron inclusions. These variations were not objectionable. Figure 19 shows the clarities of waters stored in stainless steel and tinned tanks for 30 days. There

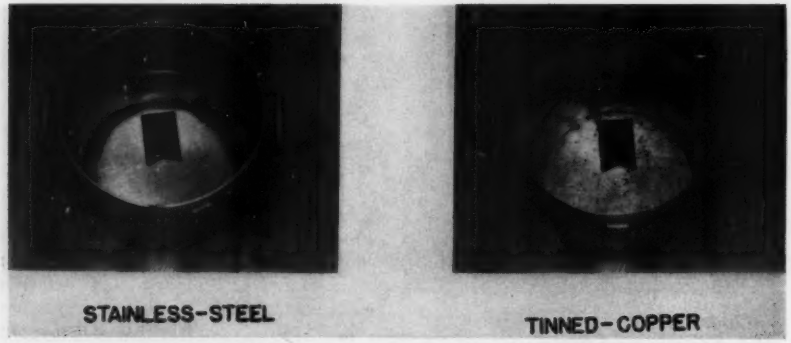

FIG. 19—Water Clarity, Tin and Stainless Steel Tanks (30 Days).

was no evidence of turbidity or discoloration in either case.

This investigation of coatings and corrosion resisting alloys did not cover all of the possibilities by any means. However, it did include the materials which appeared to be feasible for submarine use at the time of study. While the results showed that storage tank contamination could be prevented, no wholesale change to stainless steel or tin was made for economic reasons. Table 5 shows a data summary for the contamination studies.

TABLE 5— TANK METAL CONTAMINATION OF DISTILLATE

Exposure	Pure Aluminum	Aluminum Alloy	Copper Nickel (70-30)			Inconel		Monel			Pure Nickel	Stainless Steel (18-8)			Tinned Copper	
	Al	Al	Cu	Fe	Ni	Fe	Ni	Cu	Fe	Ni	Ni	Cr	Fe	Ni	Sn	Cu
Pure Distillate																
5 days	—	—	0.7	zero	0.6	zero	0.47	zero	zero	0.54	2.5	0.01	zero	0.11	zero	zero
30 days	1.9	0.16	0.87	zero	2.0	zero	0.56	0.05	zero	1.66	4.4	zero	zero	0.21	zero	zero
Distillate + 5 ppm Chloride																
5 days	3.0	0.08	0.36	zero	0.70	zero	zero	zero	zero	0.31	0.41	zero	zero	zero	zero	zero
30 days	6.8	0.30	0.31	zero	2.30	zero	0.09	zero	zero	1.1	1.45	zero	zero	0.07	zero	zero
Distillate + 5 ppm Chloride + CO_2																
5 days	6.4	5.8	6.6	0.06	14.9	0.30	2.43	1.1	0.06	61.5	106	zero	0.11	—	zero	zero
30 days	19.0	9.2	4.8	0.06	27.6	0.25	1.76	4.0	0.06	173	89	zero	0.08	0.23	zero	zero

DEMINERALIZATION OF BATTERY COOLING WATER

A decade after the vapor compression still took water off the critical list of the submarine, its distillate was put to a new, range extending use, battery cooling. A review of the battery characteristics and their relation to military operation shows the importance of this development.

Submarine storage batteries generate considerable heat by chemical reactions and formation of molecular hydrogen and oxygen during charge and by elec-

trical resistance of the electrolyte, the plates and the conductors during both charge and discharge at high rates. Temperatures above 130°F promote self-discharge and hydrogen evolution between charges, lengthen the charging time and cause serious water losses. They reduce battery life by causing sulfation of plates, "moss" short circuits, and rapid attack of positive grid members. When operating in tropical waters, limiting the battery temperature to 130°F often results in partial charges, or cooling periods up to 36 hours. Both are impracticable during wartime. In the past, battery cooling was provided entirely by air ventilation of the cells. This process cooled almost entirely by evaporation of the battery water and carried considerable acid spray into the vent lines. It was too inefficient for proper cooling in the tropics.

In 1951 Portsmouth Naval Shipyard installed experimental water cooling systems on the batteries of the USS *Burrfish* (SSR-312) and the USS *Cutlass* (SS-478). The former was a "home-made" unit, and strictly experimental. The equipment on the *Cutlass* was designed specifically for the intended use. It consisted of a shell and tube, 70-30 copper-nickel heat-exchanger with pumps for circulating sea-water through the exchanger tubes and distillate through the exchanger shell, the connecting lines and the hollow channels in the lead battery straps.

The connecting lines and headers were made of copper and were insulated from the batteries with rubber hose. A 20-gallon surge tank was included in the circuit. The distillate circuit held about 100 gallons of water. This was circulated at a rate of 125 gpm, while pumping the sea-water coolant at 250 gpm. The system was equipped with flow indicators, thermometers, conductivity meters, (distillate side) and a heat-exchanger by-pass arrangement for controlling distillate cooling and therewith battery temperature. There also were direct reading battery ground meters to indicate the extent of battery "shorting" by impurities in the distillate. A flow diagram of the pump room and one battery compartment is shown in Figure 20. The cooling circuit of the lead battery straps is shown in Figure 21.

Preliminary trials of the battery cooling system on the USS *Cutlass* were both encouraging and disappointing. The system was very successful from the heat balance standpoint, but conductivity in the fresh cooling water, and objectionable battery ground developed very rapidly. It was necessary to flush the distillate side of the cooling system after 36 to 48 hours of operation in order to remove contaminants. Because of the rather complex arrangement of pipes and tubes, this required very large quantities of distillate (several thousand gallons). Station water technologists investigated this problem during anti-submarine warfare maneuvers at Key-west, Florida in May 1951. They found that contamination was resulting from gradual solution of copper and nickel in the heat-exchanger. The nickel content alone increased from 3.5 to 10 ppm in 24 hours of circulation. With the heat-exchanger by-passed, it increased from 3.5 to only 6 ppm. The relatively high original concentration of nickel (3.5 ppm) resulted from the fact that shore distillate was used in filling the system. Figures 22 and 23 show the rate of increase in nickel content and conductivity of the distillate in this trial.

This problem of nickel pick-up resembled the earlier problem of battery water contamination. However, it could not be solved with the cation exchanger, which reduces metal content without reducing conductivity. The problem was further complicated by the fact that the full flow rate of 125 gpm could not be handled with an exchange of tolerable size. A monobed ion-exchange demineralizer, operating in a parallel loop to provide continuous dilution of both metal and non-metal ions appeared to

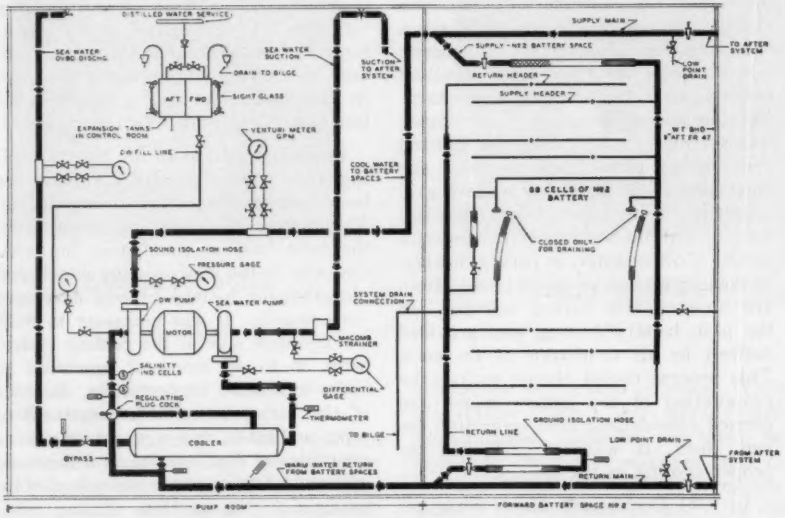

FIG. 20—Battery Cooling System, USS *Cutlass* (SS 478)—(1951).

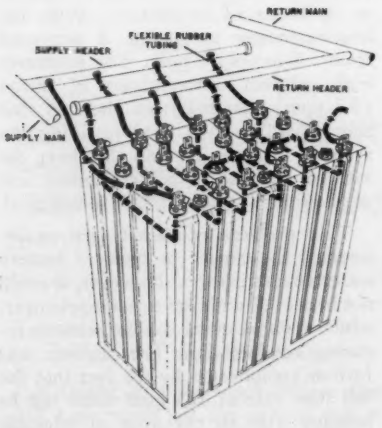

FIG. 21—Cooling Circuit in Battery Straps.

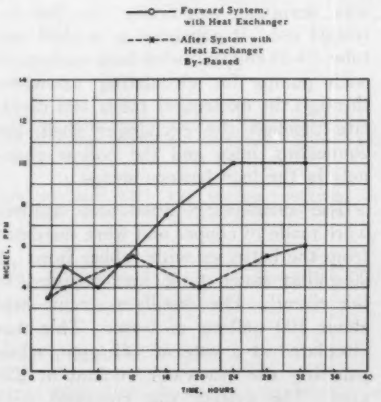

FIG. 22—Nickel Pick-up in Cooling System.

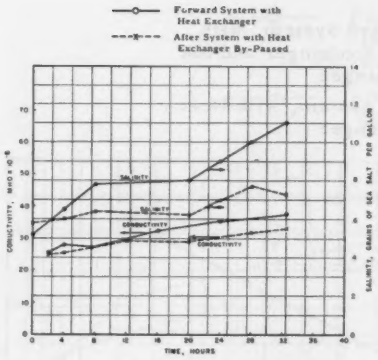

FIG. 23—Conductivity and Salinity Indicator Reading Cooling Water.

be the only practicable solution. Demineralizers of this type are relatively new developments in the ion-exchange field. They consist of intimate mixtures of anion and cation exchange resins, generally in the form of spheres approximately 0.5 millimeter in diameter. Examples are shown in Figure 24. The cation exchange material is generated with acid and exchanges hydrogen ions (H^+) for heavy metals, while the anion exchange material is generated with

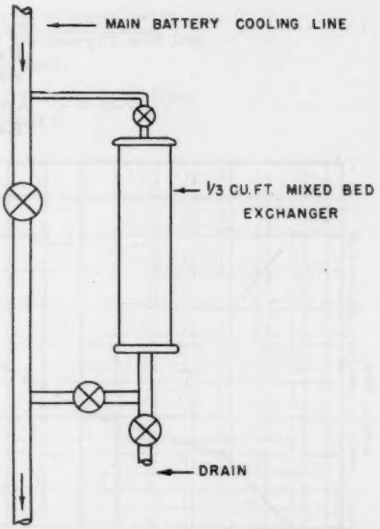

FIG. 25—Arrangement of Mixed Bed Exchanger.

caustic and exchanges hydroxyl ions ($(OH)^-$) for non-metallic ions such as chloride, carbonate and sulfate. The H^+ and $(OH)^-$ ions combine to form water, so that pure water is the only

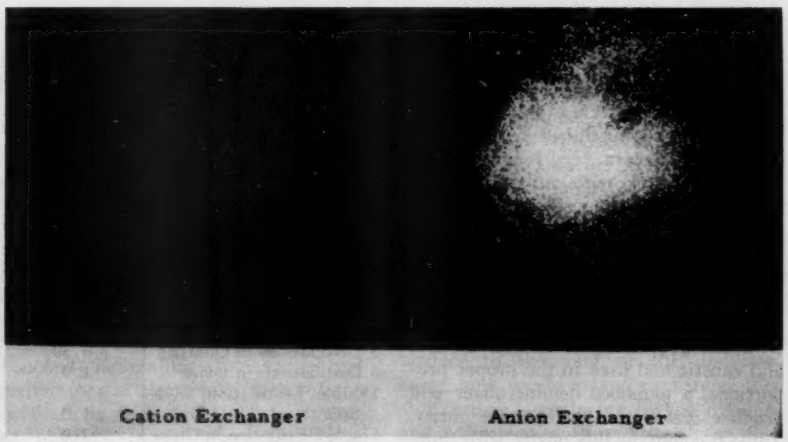

FIG. 24—Typical Mixed Bed Exchange Resins.

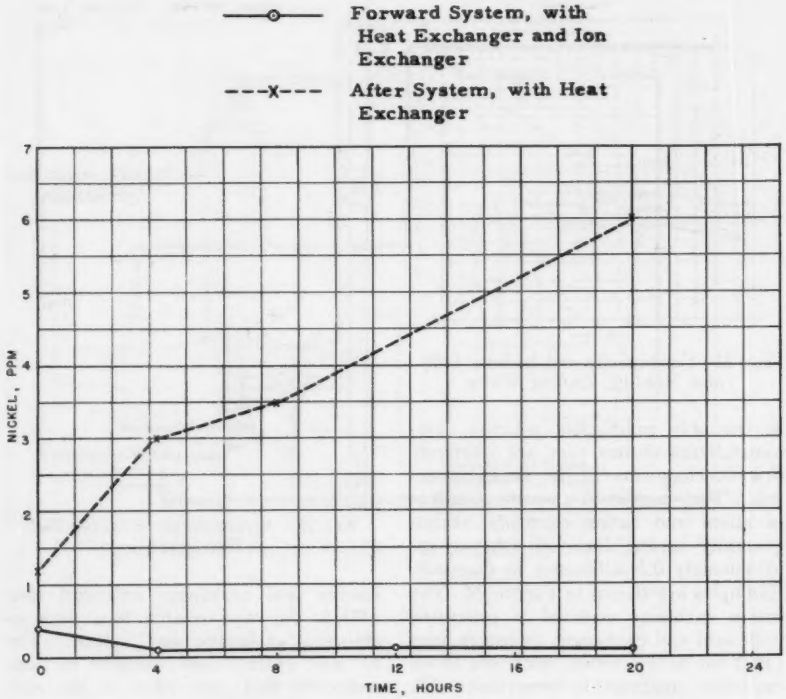

FIG. 26—Effect of Mixed Bed on Nickel.

product of the perfect demineralizer. Because of the mixed-bed arrangement, the water makes a very long series of alternate contacts with cation and anion particles in passing through a few inches of the exchange bed. This insures complete demineralization even though the exchange in a single contact is not 100%. When manufactured from the proper resin materials, regenerated with the proper concentration of acid and caustic and used in the proper proportions, a monobed demineralizer will produce water of unbelieveable purity. Table 6 compares this purity with those obtainable by other standard techniques.

TABLE 6—PURITY OF DISTILLED AND DEMINERALIZED WATERS

Treatment	Conductivity, Mhos x 10^{-6}
28 Distillations in Quartz	0.05
Mixed Bed Ion Exchange Demineralization (optimum)	0.06
3 Distillations in Quartz	0.50
3 Distillations in Glass	1.0
Double Distillation, X-1 Still	1.0
Single Distillation in Glass	2.0

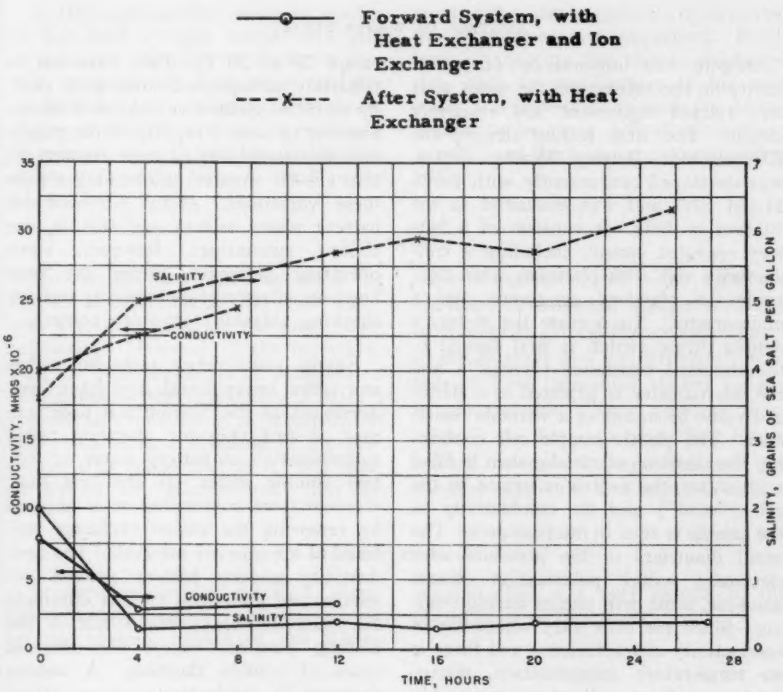

FIG. 27—Effect of Mixed Bed on Conductivity.

The tests on the USS *Cutlass* were made with a monobed of highly basic Permutit S and highly acid Permutit Q resins in the proportions of 3 to 1. A regular 1/3 cubic foot, submarine exchange cylinder of the mixture was attached to the cooling circuit as shown in Figure 25. It is estimated that approximately 1% of the water was bypassed through the bed. This solved the contamination problem. Figures 26 and 27 show the remarkable reductions in nickel content and conductivity. An extended service trial showed that the monobed maintained the same high purity for at least 30 days. Later installations with tinned heat-exchangers obtained much longer periods of trouble free service.

No effort has been made to reclaim the exhausted monobed material, which costs approximately $30.00 per 1/3 cubic foot cylinder. It is difficult to separate and regenerate the resins either aboard ship or in Naval depots. By using tin coatings or stainless steel on all metal parts of the distillate system it should be possible to extend the life of a single charge to 6 months or a year, in which case the loss in discarding the monobed would be insignificant. Attaching a rubber expansion bulb or bladder to the vent of the distillate surge tank would extend exchanger life still further by reducing carbon dioxide and dissolved-oxygen attack on the metals.

CONTROL OF WATER PURITY

Despite the importance of water purity on the submarine, the water tests and related equipment are relatively simple. The first testing device, the Kleinschmidt Battery Water Tester, was developed concurrently with the S Model Still and was evaluated at the Station in 1942. It consists of a battery operated circuit, including a conductivity cell with platinum wire electrodes, a standard resistance and a microameter. To operate the tester, a double throw switch is first turned to the standard resistance ("check") and the microameter is adjusted to a standard value by means of a variable resistance. The plastic sample cell containing the platinum electrodes then is filled with water, the switch is turned to the cell ("read") and the conductivity of the sample is read in microamperes. The small diameters of the platinum wire electrodes reduce polarization effects, however, some drift occurs during reading. Since the cells vary somewhat in conductivity characteristics and there is no temperature compensation, microameter readings will vary appreciably from one cell or temperature to another. For example, a group of 4 cells at the Station showed readings from 53 to 73 microamperes with 5 ppm chloride solution (as sea-salt) over the temperature range 20 to 30°C. This variation is relatively unimportant since good quality distillate yields a reading of 8 microamperes or less. Fragility of the plastic cells and possibility of their contamination are far greater disadvantages than these variations. Many Kleinschmidt battery water testers are still in use aboard submarines, however, some operating personnel prefer the time honored, silver nitrate turbidity test for checking chloride (sea-salt) content.

Simple colorimetric tests for nickel and other heavy metal ions have been developed at the Station but none are used aboard ship for checking metal contamination of battery water or battery cooling water. In the first case, freedom from contamination is assured by renewing the cation exchange material at appropriate intervals. The conductivity meters, battery ground detectors and automatic signals eliminate the need for heavy metal test in the cooling circuits, except for unusual cases of trouble shooting. A sudden increase in conductivity means either sea-salt from the heat-exchanger or metal from an exhausted ion exchanger. The silver nitrate test will distinguish between these contaminants so that no extra gear is necessary.

A LOOK INTO THE FUTURE

The colorful history of progress in submarine water purification shows no sign of ending in the near future. Tests already have been made by a research contractor on an "electrodialysis unit" capable of producing high purity water from sea-water without high temperatures, moving parts, noise or regeneration treatment of any kind. The basic principle is the opposite of that by which the electric eel generates current. Sea-water is flowed between ion selective, plastic membranes, which in turn are situated between positive and negative electrodes. The electrodes pull the positive (metal) and negative (non-metal) ions to opposite membranes by electrolysis. The cation (positive) selective membrane transfers the metal ions of the sea-salts to the outside of the cell where they can be flushed away with waste water. The anion (negative) membrane transfers the non-metal ions in the same manner. Eventually all of the sea-salts are outside the membrane cell and pure water is within.

A 1000 gpd purifier would be smaller in size than a vapor compression still of the same capacity. It would be capable of supplying 2 or more qualities of distillate by tapping various stages of the purification process. It even may be possible to separate the purification stages and scatter them in small nooks so that the larger spaces are available for other important equipment. Problems of adapting this unit to shipboard use, such as sterilization of the cold water and prevention of sludging do not appear to be more difficult than those which faced the first vapor compression still.

CONCLUSION

No one will deny that necessity is the mother of invention or that fresh water was a critical item for the long range submarine. However, if the inventiveness of this development program is discounted by the necessities of war, a considerable measure of accomplishment still remains as a dividend to the personnel who cooperated in it. The conviction of Dr. Kleinschmidt that the vapor compression still would work, the unbiased development studies of Navy technologists, the confidence and support of the Bureaus and the patient cooperation of Fleet personnel shared equally in the mission. This type of team work is the best insurance that future critical needs of the Fleet will be handled efficiently and expeditiously.

ACKNOWLEDGMENT

Information supplied by R. C. Bartlett regarding Station development tests on the various models of the Kleinschmidt Still was very helpful in the preparation of this paper.

CONTROL OF INTERNAL CORROSION OF TANKERS

ACKNOWLEDGMENT

This paper was presented at the Annual National Petroleum-Mechanical Engineering Conference of The American Society of Mechanical Engineers held during September 1953 in Houston Texas. Its authors were MR. WILLIAM B. JUPP, Marine Transportation Department of Socony-Vacuum Oil Company, and CAPTAIN CARL J. LAMB, USNR. Captain Lamb was released to inactive duty in January 1954, but at the time of writing this paper he was Supervising Inspector of Naval Material, Houston, Texas.

At the 1952 Annual Meeting of the Society of Naval Architects and Marine Engineers, one of us, Mr. Jupp, presented a paper, "The Nature of Corrosion and Its Control," and the other contributed discussion. Since that time additional data have been obtained from the MSTS and the Bureau of Ships of the Navy, and the paper presented herewith is composed of a compilation of data from the three sources.

The control of internal corrosion of tankers is of equal and vital importance to both commercial tanker operators and to the Navy. The principal savings to both are: 1. Reduced maintenance costs; 2. Reduced use of steel; 3. Increased life of tankers; 4. Reduced contamination of cargoes due to bulkhead or boundary failure.

As might be expected, corrosion in the cargo spaces of tankers exhibits wide variations, dependent upon the trade routes, the types of cargo carried, and the frequency of ballasting and cleaning tanks. Vessels operating exclusively in fresh water show a low rate of corrosion, regardless of the types of cargo carried. Some river barges and tankers on the Great Lakes have required no repairs to the cargo spaces during upwards of 14 years in service, even though in clean trade during the majority of the time. On the other hand, vessels operating in salt water have developed serious bulkhead failures in six to eight years of clean trade, have required frequent cleaning.

A study of tankers operating in the ocean and coastwise trade should furnish the best data on the cost rate and nature of corrosion, as well as points of greatest attack. The data and comments given herein are based primarily on the analysis of corrosion gathered from some twenty ships, some riveted, some welded, all operating in the Gulf-East coast trade, and alternating between clean and dirty cargoes. If a tanker is to make its anticipated twenty-year life, in the above trade, half in the clean service and half in the dirty service, the data presented would indicate that it will be necessary to renew completely all internal structure in this period, with partial renewal of deck

and bottom plating and also with some renewals of framing.

A recent estimate for the complete renewal of internal structure of cargo space indicated that this would cost a minimum of $750,000. Work on the partial renewal of deck, shell and bottom plating, including some longitudinals, could not be covered for less than $250,000. In round figures the expenditure for steel work to maintain a twenty-year life (one half in dirty and one half in clean trade) would be in the neighborhood of $1,000,000 for 500 cargoes between Gulf/North of Hatteras. It will be assumed for the moment that corrosion is three times as rapid in the clean trade as in the dirty trade. It therefore follows that if the 500 cargoes are operated as 250 clean and 250 dirty, the corrosion cost of the clean cargoes is $750,000, or $3,000 each, and of the dirty cargoes is $250,000 or $1,000 each. Looking at it another way, the 250 dirty cargoes at one-third the corrosion rate would be equal to one-third this number of clean cargoes or 83 cargoes. These 83 equivalent clean cargoes added to the 250 clean cargoes would make an equivalent of 333 clean cargoes in the 20-year life of the ship. Most of this expenditure is, of course, in the second half of the ship's life. It can be expended on a year-to-year basis or in one or two major overhauls.

To place this figure in another light, in a fleet of 20 ships in such service, the cost would be $1,000,000 per year or $50,000 per year per ship, $75,000 per year for the clean trade and $25,000 per year for the dirty trade. This expenditure does not include the cost of cargo piping, valves, reach rods, ladders, etc.

In the early thirties, the ships of the summer-tank type built during and immediately after World War I were carefully drilled to determine the necessary steel renewals to extend their life. These data were analyzed in an effort to determine the rate of corrosion. An effort to plot the amount of wastage against time or number of cargoes gave a very good plot when a time scale was adopted using time in the dirty service evaluated at a corrosion rate of one-third that of clean service.

It will be noted that at the end of nine years of service, where three years of dirty trade equals one year of clean trade, the average corrosion was 0.10 in. or a rate of 0.011 in. per year, on a clean trade basis. In the next six years, however, the corrosion had accelerated to an average of 0.015 in. per year, an increase of 35% in the rate of corrosion. The external or shell plating corrosion average is very close to that of the internal members, although it is exposed to cargo on one side only. This is due to the very high rate of wastage under deck. When the deck wastage is averaged with the shell wastage the result as stated above is very close to average wastage of the internal members.

The general wastage is noted in percent of the original thickness for various thicknesses of plate, as well as actual loss, as renewals usually are required when the general wastage exceeds 25% of required scantlings, particularly in the shell. Rebuilding becomes absolutely essential in any part of the structure before it reaches 40% because of the much higher rate of wastage when the material dimensions are so far below those of the designed scantlings.

The wastage data on ships built after the mid-thirties also have been plotted. They show the same rate of corrosion as the older ships when plotted on this scale. Their higher speed, however, represents 25% more cargoes carried in the same period. These new ships have had some treatment of inhibitors after tank cleaning which may be a factor in the increase in cargoes carried.

Several of the new ships had about 0.04 in. extra thickness of steel added to the upper structures, and therefore the percentage loss below the required scantlings in such cases must be replotted when consideration is given to renewals. The increased scantlings in plates under one-half inch in thickness required about 60 to 80 tons of metal. It has resulted in increased life of about four years, before requiring replacement.

The wastage data used to determine the general corrosion rate were analyzed again to determine the relative loss of metal in the various parts of the structure. A number of modern tankers were used for this purpose. The data correspond closely to that of a previous study of the old summer tank ships. The average wastage of the shell is not far different from that of the bulkheads although only one side is exposed to the cargo. The greatest wastage is found in the deck plating and framing—even greater than of the bulkheads.

The bulkheads and their framing show a difference in corrosion rate of only about 10% more in the upper spaces than at the bottom. This is roughly in inverse proportion to the thickness of the plates and also is true of the general corrosion curve, indicating that fatigue corrosion may be a factor. When these wastages are put on a percentage basis, the picture changes, showing a much higher percentage in the lighter upper cargo structure and deck plates and frames. It also is of interest to note that the corrosion is greater where the steel is exposed to moisture and sweating due to changes of temperature caused by heating in the sun, cooling at night, etc.

It was impossible to find excessive corrosion in the tanks normally used for ballast. If corrosion due to sweating is a predominating factor, as indicated by these figures, one would anticipate the greater corrosion on the empty side of a ballasted tank where both moisture and oxygen are present. It is well known that both are required in normal corrosion and the rate of corrosion is much greater with a high oxygen content than when the amount of oxygen is restricted, as in a ballasted tank. It has been pointed out very clearly that there is need of maintaining a pH value of the moisture film in contact with the steel of at least 10 to lower the corrosion rate in the presence of oxygen.

Data from two ships operating on the West Coast, where less cleaning and gas freeing are required with a consequent lowering of the moisture in the tank, show a decidedly lower rate of corrosion. No difference was found in the corrosion rate of ballasted tanks as compared with the tanks normally empty on the ballast run.

Local corrosion unfortunately is not of equal intensity throughout each of the various panels between stiffeners making up the bulkheads, but is as much as three times as rapid at the points of maximum working, or hard points, in the general structure. These points cause failures in cargo segregation long before the general corrosion gives difficulty.

The maximum local corrosion occurs at hard points or the points of maximum flexure or strain; that is, at the points of working of the structure or the points of high cyclic stress, not necessarily at the parts of the structure under the heaviest load or stress. In other words, a distinction must be drawn between uniformly distributed stresses and local hard points where cyclic stress or fatigue play an important part.

There is noticeable grooving of the bulkhead plate above a web or horizontal stiffener. This local corrosion is particularly aggravated at the limber hole in the horizontal web. The web itself is grooved in the same manner. These grooves may run toward a lightening hole. This condition is not found

TABLE 1—CORROSION RATES

Type of Cargo	CONDITION OF TANKS			
	Loaded	Ballast	Empty	Cleaned
White Products	Minor	Moderate	Major	Maximum
Light fuels	Minimum	Minor	Moderate	Maximum
Crude and heavy fuels...	Minimum	Minor	Minor	Maximum
Sour crudes	Moderate	Major	Major	Maximum

on the bulkhead under a web stiffener. The usual shallow pits, however, are present as in other parts of the structure.

It has been found that the same effect occurs on a fluted bulkhead where the shape of the sides of the flute allow this flexuring to take place in the middle of the panel. Here a section in the middle of the panel is reduced to about one-half that at the knuckle of the flute. This type of corrosion requires expensive patching before the structure as a whole has failed to a point requiring renewal.

The same situation exists at the bracket through bulkheads for shell longitudinals. This condition does not occur at brackets adjacent to a cargo pipe through the bulkhead because they help to stiffen the plate at the nearby brackets and thereby restrict the working of the plate.

Cyclic stresses or fatigue alone may account for these very rapid failures. In each case the scale was broken (presumably due to flexure or working of the plate). The condition in each case was more marked on an upper surface of a horizontal stiffener than on the underside, or on a vertical stiffener. This holds true on brackets with their points up rather than on deck longitudinal brackets with their points down. At first this appeared to be due to an accumulation of loose scale and the consequent moisture. Recently, in scaling a section of a bulkhead, it was noted that a considerable amount of moisture drained from the scale immediately above. This moisture could contain concentrated brine or other material to make it a strong electrolyte. If this is so, it would help explain these local failures.

Pitting plays its part in corrosion. The pits do not tend to progress on the vertical surfaces, as the scale breaks free before deep penetration occurs. This is not equally true on the bottom plating where this condition can become very troublesome, particularly when carrying sour crudes. As sour crude pitting is not considered a major corrosion deterioration problem on the majority of tankers now in operation, which indicates the over-all average corrosion penetration plotted on an adjusted time basis.

It would be helpful to know when the corrosion is most active. Does gasoline alone cause corrosion? Is ballast the worst offender? There are considerable data indicating that moisture with a low pH value and high oxygen content will produce the most rapid corrosion unless the residual cargo protects the steel.

Table 1 summarizes these conditions.

The cargo, whether clean or dirty, is an excellent insulator and it inhibits corrosion where the tank is loaded with cargo. The heavier petroleum leaves a coating on the steel which gives protection in an empty tank. Gasoline, however, cleans the steel and exposes it to corrosion when moisture is present.

Cleaning with sea water adds moisture and accelerates the rate of corrosion.

The above data, in conjunction with the well-known theories of corrosion, indicate that the assumptions reached appear to be logical. Here are indicated, we believe, some of the points where research and controlled tests aboard ship could help in giving precise answers to such questions as:

1. What percentage of the over-all corrosion occurs under the various conditions of cargo-ballast-clean, etc.?

2. What is the difference in corrosion between the plate not under strain or not working and that of one subject to high strains or flexing under load?

3. Does the rough surface of an already corroded plate increase its rate because of the increase in surface, or is the increasing rate of corrosion due to its greater unit stress?

4. Does the breaking away of scale at the points of flexure in itself affect the rate of corrosion?

5. What percentage of the corrosion occurs on the side of the plate carrying ballast and in the empty tank due to sweating from differences of temperature of the ballast and the empty tanks?

6. Would the removal of scale reduce or accelerate the general corrosion?

7. What effect would an occasional fresh water wash of the rusted bulkheads have on removing brine and how would this affect the corrosion rate?

8. What is the chemical analysis of the water retained in heavy scale under varying operating conditions?

9. What is the corrosion rate of steel in a hot salt saturated atmosphere, in comparison to a steam saturated atmosphere?

METHODS OF CORROSION CONTROL

There have been many methods of approach to reduce this costly corrosion. To oversimplify these methods, they can be classed in two types:

(A) Mechanical approach
(B) Electrochemical approach

Table 2 shows the two approaches with three subheads under mechanical:

(1) Coatings
(2) Design
(3) Materials

and four subheads under electrochemical:

(1) Oxygen elimination
(2) Moisture elimination
(3) Chemical inhibitors
(4) Impressed potential

These various methods are not all equally effective under the various conditions of cargo-ballast-empty-clean, etc. If the relative rates of corrosion mentioned earlier are accepted it is then desirable to use the methods best adapted to control corrosion when oxygen and moisture normally are present, that is, when the tanks are empty or clean. (Sour crudes, with their high sulphur, require special treatment to control hydrogen sulphide corrosion in the upper spaces and acid corrosion on the bottom plates.)

The three mechanical approaches are all effective regardless of the tank condition, provided they can be successfully applied.

Coatings have probably been experimented with more than all other methods. The most common failure has been the lack of adhesion and inability to obtain a clean surface for application of the coating. The necessity of maintaining a firm coating under cargo ballast and hot salt spray when cleaning offers many problems. If the coating is porous or cracks, rust will form behind the coating and destroy its adhesion. Sample patches for test under

TABLE 2—TYPES OF CORROSION CONTROL

Corrosion control	Effectiveness of various methods of control			
	Loaded	Ballast	Empty	Cleaned
Mechanical:				
Tank coatings				
Structure design		EFFECTIVE		
Structure material				
Electrochemical:				
Eliminate oxygen	No	No	Yes	Yes
Eliminate moisture	? Yes	No	Yes	Yes
Chemical inhibitors:				
In cargo	Yes	? ?	? Yes	? No
In ballast water	No	Yes	No	No
Sprayed inhibitors	No	No	Yes	Yes
Impressed potential:				
Metallic anodes	No	Yes	? ?	? ?
Metal spray	Yes	Yes	Yes	Yes

careful control of application usually give better results than large-scale application. A recent test of a vinyl coating gave favorable results.

Coatings in the cargo spaces of vessels operating exclusively in fresh water have been satisfactory, particularly where all ballast is carried in double bottoms. A well-known tanker fleet operating in fresh water has successfully applied raw linseed oil for many years.

Sprayed metal has shown good adhesion provided the surface is properly prepared. Rust is inhibited behind the sprayed metal and it, therefore, tends to retain its adhesion. Metal spray can be classed also under the heading of "Impressed Potential" and will be dealt with later.

Carefully applied coatings during construction over the limited surfaces subject to high rates of corrosion fatigue should be helpful even if the coating is effective only for a limited time. The applications to these points before erection have time to harden and can be applied at less cost than later.

The summation of W. W. Cranmer's excellent paper, "Gasoline Resistant Tank Coatings," is worthy of serious consideration, and is quoted:

"Serious corrosion of mild steel occurs when refined petroleum products, such as gasoline are transported in bulk in tankers. One approach to this problem is to apply organic protective coatings. A program directed by the Industrial Test Laboratory, Philadelphia Naval Shipyard, Philadelphia, Pennsylvania and sponsored by the Bureau of Ships, Department of the Navy, has shown that coatings based on a vinylidene chloride/acrylonitrile copolymer are suitable for this purpose. These coatings dry by solvent evaporation, and require clean metal surfaces and careful attention to good safety practices during application. When multiple coats are applied to a total thickness of about 0.008 inch, it is estimated the coatings will be adequate for four years against the combined effect of sea water and refined petroleum products, or equivalent corrosive conditions; and that touch-up at intervals of four years

will extend the life expectancy of the coating indefinitely. Since the coatings are air-drying and somewhat cheaper than various heat cured materials now used to protect tank car interiors and various types of equipment, it is recommended that they be investigated by industry for such uses."

The Bureau of Ships, in order to reduce corrosion of gasoline tanks in steelhull AO, AOG, YO, YON, YOG, and YOGN ships, has approved application of vinylidene resin coating, Bureau of Ships formula 113, standard Navy stock numbers 52-R441-625 and 52-R-442, to all interior surfaces of these tanks on active ships.

MSTS has investigated the application of protective coating to the interior of the cargo tanks, utilizing the experience of the Bureau of Ships and commercial tanker operators. The cost of applying organic coatings such as SARAN has appeared prohibitive up to the present time, thus no service applications have been made or planned by MSTS. However, one experimental application of a metallic base paint formulated with finely divided aluminum particles has been made in one of the AOG type tankers under MSTS operations. Sufficient data have not been collected to permit an evaluation of this type of material. It is possible that here again the cost of applying the coating may make its use unattractive as in the case of SARAN.

Several oil companies have obtained excellent results in pipe line, tank and tank car corrosion control by the use of neutral chemical inhibitors placed in the bulk liquid. One company has increased the pipe line cleaning cycle from three months to eighteen months. It has been found that the inhibitor in the oil also reduced corrosion in storage tanks and tank cars. Whether such inhibitors will be effective in tankers remains to be seen, since it is not known that their use can be depended upon during the empty or ballasted condition.

Design has made some progress, particularly in the reduction of some of the major hard points. The local hard points of maximum flexure or strain in the bulkhead plating have caused very high corrosion rates and local cracks. These points are of primary importance and require correction if a normal life is required in the internal structure in the cargo spaces because:

(1) this corrosion fatigue rate is two to three times that of normal corrosion, and,

(2) it results in cracks which may propagate and cause serious failures of the structure or at least interfere with the segregation of different cargoes in adjacent tanks.

A pamphlet issued by the American Bureau of Shipping several years ago suggested methods of modifying the design to reduce this difficulty.

Some methods for the correction of local hard points, not in common use, but now under test, are proving effective, at least in the early stages of the tests. The long "V" shaped doubler at the points of brackets prevents the concentrated flexure of the bulkhead and avoids the accelerated corrosion.

The flat bar stiffener in the flat panel of the fluted bulkheads acts as a tripping bracket to the side of the flute. It should stop the flexure of the panel and retard its accelerated corrosion and cracking.

The wastage on the upper side of the horizontal webs and stiffeners is difficult to control. The fact that it occurs on the upper side only indicates that a strong electrolyte is draining from the scale above and with the ability to pick up oxygen where the scale has been broken away, together with the cyclic stresses, leads to an early failure at this point. Long diamond doublers or brackets on the top of the web should help control this wastage. Limber holes in webs have produced early failures

in the webs. Coatings of sprayed metal and vinyl are under test in an effort to reduce the local corrosion.

Design can also consider an increase in dimensions of scantlings which require the earliest renewals. The data shown in the midship section and typical bulkhead indicate that the addition of 50 to 100 tons of steel in the upper sections will increase the useful life of these members by as much as four years, or 25%, before renewal becomes necessary. Recent corrosion data on several T-3 type tankers, where scantlings were increased by a total of 75 tons, resulted in an increase of several years of life of the upper portions of the structure, sufficient to extend their life to that of the lower portion of the bulkhead. These tankers already exceed the total of 120 clean cargoes which was the average carried in the old fleet before major bulkhead repairs.

Some of the special steels have been under experiment. The nickel copper steels have been used to reduce corrosion in acid conditions and indicate some advantage to be gained in tanker design. A small tanker operating partially in salt water and partially in fresh water, with a special steel middle body which shows 30% reduction in the corrosion after 14 years of service when compared to sister ships in the same trade built of mild steel. This middle body was built to the same scantlings as the sister ships.

A similar test is now in progress in a group of large barges. Three barges are built of mild steel. The fourth barge is built of special steel in which advantage was taken of its high tensile strength to reduce the scantlings by about 15 per cent.

Referring again to Table 2, the electrochemical approach to inhibiting corrosion has received much more consideration during the postwar period than before. The corrosion taking place in tanker operation is dependent mainly upon water and oxygen in contact with the steel. The water need be only an infinitesimal film which may be more active than actual submergence of the steel because of the easy access of oxygen. If this water film can be removed or given a pH value in excess of 10, the corrosion is greatly retarded. Acid corrosion also may be a factor when carrying sour crudes but appears rather minor in normal tanker operation. Strain or flexure at hard points in the steel accelerates the corrosion rate at those points.

Based upon data used by some of the commercial shipyards, the normal and inherent rate of electrochemical corrosion of unstressed steel at 75°F. in sea water appears to be approximately .015 in. per year, if no other metals be present. It should be noted here that electrochemical corrosion of a single base metal, in this case ferrous, will depend upon several factors in the metal. Ions normally will travel from hard spots to softer spots, from rough surfaces to smooth surfaces, from parent metal to nonferrous segregations, and from stressed to unstressed areas, exactly as though they were traveling from one metal to another metal. In order to reduce or eliminate marked and excessive corrosion at local hard points, it is apparent, therefore, that a primary step in the right direction is to eliminate the hard point if possible. It should be remembered, however, that in the case of a single metal immersed in an electrolite, the positive ions from that metal can enter the solution only when an equal number of positive ions of some other element are displaced in some manner, in the specific case of steel in contact with an electrolite, the element which is displaced is hydrogen which gathers on the surface of the steel as a thin, protective layer, and when this film of hydrogen has formed it insulates or prevents the further progress of the corrosion action. However,

this hydrogen film may easily become removed either by joining oxygen in solution in the electrolite, or by displacement due to motion of the electrolite, resulting from flow, agitation, etc.

When the hard points were metallically sprayed with zinc, the ion flow would be from zinc to steel. It is noted that sufficient zinc oxide was formed in such a case as to possibly degrade the quality of gasoline or clean oil being carried. It is also of interest, that since steel is more electropositive than lead in galvanic series, there is a very distinct possibility that some of the excessive internal corrosion of tankers carrying high octane rating gasoline may be due to ion flow from steel to precipitated colloidal lead.

Since magnesium is the most active of the commonly used elements in the galvanic scale, the possibility is suggested of placing magnesium angles, held, for example, by welded steel clips and wedges along the vertical and horizontal boundary angles of all tanks, and possibly in nearest possible proximity to all hard spots. This is suggested due to the greater efficiency and consequent more rapid flow of the magnesium ions, the greatly reduced weight of magnesium as compared with zinc for the same surface area and volume and a possibility that the magnesium oxide formed might not degrade high octane rating avgas to the extent found with the zinc oxide.

Some of the methods for the electrochemical control of corrosion are affective under all the various operating conditions but others are not. This is shown in Table 2. The elimination of oxygen usually is effective only in an empty tank. It could be made effective in the vapor spaces in a loaded or ballasted tank. The elimination of moisture can, of course, be effective only in a tank free of ballast. Raising the pH value of the water or the mositure can be applied either to ballast water or the moisture in an empty tank or in a clean tank; each of these three approaches requires a different method of chemical treatment.

Impressed potential or galvanic protection can be made effective in a ballasted tank. In time this might plate a protective coating on the steel. This coating has not yet been proved effective for any length of time in protecting the steel from corrosion after the impressed potential is eliminated.

We have had the opportunity, in conjunction with the Industrial Manager of the Eighth Naval District, of observing certain tanks aboard the S.S. *Cherry Valley,* equipped with cathodic protection in the form of suspended cylindrical magnesium anodes. The tanks fitted with the cathodes were found to be unusually free of rust scale, either on the plates or in the form of loose scale on the bottoms.

MSTS has made a rather lengthy study of the corrosion control system found in the S.S. *Cherry Valley,* which incorporates the simultaneous application of two principles of corrosion control, namely, that of chemical inhibition and galvanic action. Because of the pattern of cargo and ballast operations conducted in the transportation of military cargoes, it was believed that the application of chemical inhibition to MSTS tankers would have limited usefulness as developed for the S.S. *Cherry Valley.* It is further believed that the handling and mixing of the required chemicals would create operation problems out of proportion to the value of the process. However, the matter of galvanic protection is of continued interest to the COMSTS and it is planned to make an experimental installation of magnesium anodes in one of the small tankers operated by MSTS. A decision in this respect will be reached as soon as COMSTS has obtained material and shipyard costs. It is expected that the cost of cathodic

protection for MSTS tankers will be high because of the pattern of operation by which the installation of anodes in all tanks will be required for full protection.

The use of sprayed metal anodic to the steel at the local hard points can be effective in protecting these points of maximum corrosion, whether in ballast or empty, both by preventing the moisture from reaching the steel and by reversing the potential if the moisture penetrates the sprayed metal; it also prevents the formation of pits which are stress raisers and thus cuts down the fatigue failures.

The inhibiting of corrosion is much more important when light products have been carried or the tanks cleaned because the residual film left by the heavier cargoes is generally accepted as an efficient corrosion barrier.

The first method, that of eliminating the oxygen, has been tried by the use of flue gas which also is used for inerting the explosive mixture in the tank. The process consists of washing the flue gas and passing it over calcium carbonate to remove sulphur products. This involves considerable equipment, including blowers to carry the gas through the vent or specially installed lines to carry the flue gas to the tanks.

The flue gas entering the tanks still contains some oxygen. It must be treated very carefully to accomplish a complete removal of corrosive sulphur products. This gas undoubtedly is of a high dew point because of the necessity of washing it. The tests which have been carried out have been primarily under the supervision of one company. We have no information as to its effectiveness in reducing corrosion in the cargo spaces so treated.

The second method, that of dehumidifying the air or gases entering the cargo spaces, is in operation in several American tankers and is being installed in a number of foreign flag tankers. It can be used under all cargo conditions except when in ballast or while Butterworthing. Several complete installations have been in operation for more than a year.

It is worthy of note here that one operating company carrying, principally, avgas in certain clean tankers, is using a CO^2 blanket both when carrying cargo, in ballasted condition, and empty tanks on return voyages, and when loading. We have not been informed whether the main purpose of the CO^2 blanket is primarily to reduce fire and explosive hazards alone, or whether the operators hoped that the use of an inert gas in tanks at all times might reduce corrosion.

Relative to the use of CO^2 blanket in cargo tanks, it will be observed that the Bureau of Ships has made an experimental installation of an inert gas system in two commissioned vessels; namely, the USS *Noxubee* (AOG-56) and the USS *Marias* (TAO-57). It is believed that the records of the Bureau of Ships will fully reveal the purpose of the inert gas system as well as the results obtained. In the opinion of the COMSTS, the presence of CO^2 blanket would tend to reduce fire and explosive hazards and also alleviate the hard scale condition sometimes found in cargo tanks subject to gasoline service. It should be pointed out here that the use of such a blanket, if it is maintained as planned, makes inspection of the vessel for loading gasoline or clean oil cargoes practically impossible. The CO^2 contained in the empty tank of a large tanker clouds up so that the condition of the bottom and other members in the tank cannot be observed by the petroleum inspector. MSTS regulations require that the petroleum inspector certify as to the condition of the tanks, pumps, piping, etc., to receive cargo before loading is started.

A dehumidified atmosphere above the cargo or in an empty tank prevents

condensation. It also can dry out a tank wet from recent ballast or cleaning. Removal of moisture on the tank surface eliminates galvanic action and tends to render any electrolyte inert and unable to promote corrosion. This dry atmosphere is weather air reduced in dewpoint by a dehumidifier and is delivered through cargo lines, vent lines, or preferably a separate supply line with branches to the cargo tanks. As a forced ventilation system it is used for purging and gas freeing. The manufacturers anticipate that this treatment will eliminate the need of rebuilding cargo tanks bulkheads through the normal life of the ship.

The third method, that of raising the alkalinity of the water or moisture, divides itself into several parts:

(1) In ballast
(2) Empty and gassy tank
(3) Empty and cleaned tank

In each case the fundamental treatment introduces a chemical to raise the pH value to 10 or above. Laboratory tests indicate that a reduction of corrosion to one-half is well within the province of possibility.

In dealing with ballasted tanks, the nature of the ballast water is quite important and one treatment is required for clean sea water whereas different treatments are required for each of the different harbor waters. The quantity of chemical involved makes the process quite expensive. This treatment would not take care of the void spaces at the top of the tank except possibly by splashing.

The empty tank can be taken care of by inhibiting chemicals placed in the cargo (usually gasoline), which leaves sufficient residue of inhibitor on the tank structure to be effective after the cargo is pumped out. This is a very simple method of taking care of the empty tank. The use of this method in conjunction with a gas exhauster for cleaning, instead of washing with hot salt water, is anticipated to prove quite successful. Santolene "C" inhibitor is under test at present in several ships. In the event that the tank is washed, this residue inhibitor might be removed with the washing and would require replacing.

The method of spraying an inhibitor in an empty or a cleaned tank requires a mixture of chemicals and alkaline water in a tank. It also requires the use of a stripping pump to discharge through a strainer into the smothering line and thence into the tank by the Butterworth or spray system.

The first attempt to use this method was made shortly before the last war by the use of slaked lime and water. This caused considerable damage to the pumps. Since that time sodium bichromate and trisodium phosphate with a wetting agent to penetrate the scale have been used. The effectiveness of this method has been difficult to measure due to the difficulty of routine spraying because of short ballast runs in the present high-speed ships, bad weather, tank cleaning for change of cargo, and week-end work with consequent overtime by the crew.

The results although inconclusive indicate a reduction in corrosion in spite of the facts that the treatment was carried out on an average of not more than every third or fourth voyage. The results with only sporadic treatment have indicated that the vessels could carry about 25% more clean cargoes before extensive repairs.

The method of impressed potential or galvanic protection divides itself into two parts:

(A) In ballast with possible carry-over protection to empty tanks,

(B) Local protection at the points of fatigue or high cyclic stress.

The first method has been used in some ships by placing anodes in the tank with the thought that the ballasted tanks would thus be protected. This

should be effective when in ballast. The question arises as to whether this method is of value in an empty tank. Some research work would be required to see whether the resulting deposit built up on the steel during ballast is sufficient to inhibit corrosion in an empty tank.

Another method of using an anode is now being put under test on one or two ships. This involves spraying a less noble metal on the sand-blasted steel structure at the points of maximum corrosion or local hard spots. This should be effective in an empty moist tank as well as in a ballast tank. If this is successful it should reduce the rate of corrosion at this point where it is two to three times as heavy as in the rest of the structure.

A fresh water tank wash might remove the brine concentration from the scale. This, it is believed, deserves study.

The rate of corrosion against service was compiled from analysis of more than 20 ships. The newer ships show approximately the same rate of corrosion regardless of their increased speed and ability to carry 25% more cargoes in the same time. These ships had received some limited chemical treatment. Whether this ability to carry more cargoes is due to chemical treatment or not cannot be ascertained until more information is available.

The rate of corrosion for the hard points or points of stress fatigue, which rate probably is accentuated by the drainage of the electrolyte from behind the scale, is greater than of unstressed areas. This electrolyte is undoubtedly a saturated solution of brine. If any life is to be anticipated from the structure in the cargo spaces this type of fatigue corrosion must be eliminated in the initial design or corrected as early as possible. The cost of these corrections, depending upon the design, has run between $60,000 to $100,000 per vessel. It is necessary to take care of this work before the corrosion has progressed to a point of seriously cracked bulkheads.

Over ten years ago the scantlings on some Socony "M" or "T-3" class and Maritime Commission tankers were increased in the upper parts of the cargo space. These vessels have shown the advantage of these increased scantlings by reducing the failures in this section so that the bulkheads are standing up in the upper portions equal to the structure in the middle and lower sections of the cargo space. This represents an estimated extension of life from 2½ to 4 years or a 25% increase depending upon the amount of metal added. The cost of this additional weight of metal has been about $15,000 per vessel for an extension of four years in the life of the bulkheads.

The use of special anti-corrosive steel, as pointed out, showed an extension of life in excess of 25 per cent. If the deck longitudinals and upper strakes in the cargo spaces were built of special steel, the cost per vessel for 1,000 tons of steel at $45 per ton additional, would amount to $45,000.

The early data now available on the dehumidification, chemical treatment of the tanks, and galvanic protection or a combination of some of these give every indication that we should be able to anticipate 25% to 50% increase in life by the use of one or a combination of these methods. The repair of hard points, using heavier scantlings, using anti-corrosive steel in part of the structure and the use of a treatment to inhibit corrosion, might possibly extend the life of the cargo spaces beyond twenty years, without major bulkhead renewals where the ship is operating half in the clean trade and half in the dirty trade. The cost of this is indicated as:

Correction of hard points including metal spray	$ 75,000
Increased scantlings	15,000
Anti-corrosive steel	45,000
Corrosion-inhibiting methods	65,000
TOTAL	$200,000

This cost is roughly $10,000 per year on a 20-year basis as compared to the present cost of $50,000. This indicates the possibility of saving $40,000 per year per tanker with good corrosion control. The accomplishment of this objective is now in its preliminary stages.

If the present indications for estimated extension of the life of cargo spaces by the various approaches of improved design, better material, electrochemical control and correction of hard points, live up to the present test data, we can look forward shortly to controlling this vexing and costly problem.

First of all, hard points of high corrosion must be corrected early in the ship's life otherwise early bulkhead failure will occur.

Next the number of tank cleanings with salt water must be reduced to the minimum consistent with the required service of the vessel.

Finally, research must find the best and most economical approach under the various methods. Design details can be improved by the Naval architects. Anodic protection shows real promise. Operators must carry out the proper treatment. The various interested groups working together should in the near future be able to show marked progress in the control of corrosion in the cargo space of tankers.

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ADDENDUM

Since the publication of this paper, additional data have come to our attention, which are hereby added.

Santolene "C" inhibitor has been under test for some months in several ships. These tests indicate a reduction of the corrosion rate to about one-half of that in the tanks which did not have Santolene "C" in the petroleum carried in the tanks. This is a very simple and inexpensive method of reducing corrosion. It merits further test and wider use, which should prove very valuable in corrosion control.

There is one feature of corrosion that has become paramount in the last few months and was only touched upon. It is the corrosion of heater coils, bottom plating, and horizontal surfaces in the lower part of the tank. Tests are being made at present with resin and vinyl coatings on the heater coils and bottom plating to develop a method to reduce this type of corrosion in tankers operating primarily in the Persian Gulf trade.

THE SIGNIFICANCE OF THE IZOD TEST WITH REGARD TO GEAR DESIGN AND PERFORMANCE

ACKNOWLEDGMENT

This article, appearing in the 7 August 1953 edition of "Engineering," was written by MR. J. E. RUSSELL and MR. W. T. CHESTERS.

It has long been realized by engineers that the Izod, or any other impact test, is of little use for purposes of design. The stress-system at the bottom of the notch and the rates of application of the load are so very different from what generally occur in practice under "shock" conditions, that the energy absorbed is no indication of what might occur in service. Further, there is a fairly large body of work showing that the impact-test value is quite unrelated to fatigue properties, at least for stresses in the region of the fatigue limit. Inglis [1] showed that no change of fatigue properties occurred in a Ni-Cr steel, having an original Izod value of 38 ft.-lb. after high-temperature embrittlement for many years, producing an Izod value of 4 ft.-lb. Collins and Dolan [2] could find no correlation between the Izod value or tensile ductility and fatigue (plain and V-notched specimens) on a series of carbon and low-alloy steels, and more recently Gough [3] also reported little correlation, using specimens with sharp notches, producing stress-concentration factors of up to 10.

Under conditions of fatigue under shock loading, or "smooth" loading at such a rapid rate that it can be regarded as shock, the main information in the literature appears to be that of Stanton and Bairstow [4] who used the old repeated impact test, now unfortunately discarded, and showed that where the energy of the repeated blow was in the neighborhood of the fatigue limit of energy the lives of the specimens were in strong correlation with the ordinary fatigue limit of smooth specimens determined on the Wöhler machine and independent of the Izod value of the material, but when blows of a very high energy were given, so that the specimens broke very quickly, the lives were strongly correlated with the Izod value. It would therefore appear that, from a somewhat academic point of view, there is in general little to fear from low impact values in so far as the possibility of failure by fatigue is concerned.

There remains the possibility of the failure of a structure at one sudden application of an excessive overload,

and here, in contrast to fatigue failure, no general statement can be made on the relevance of a standard impact test; each problem must be considered on its own merits. While it must be admitted that there is often little evidence on which to base such consideration, it is equally true that engineers have been prone to allot too large a safety margin to cover their ignorance, and to ask for material of high Izod value simply because shock loading (of any kind) would be occurring on the structure they were designing.

SHOCK LOADING OF GEARS

With regard to the specific problem of gear design and performance, there have been widely divergent views expressed, from time to time, on the efficiency of a high Izod value to guard against tooth-breakage by shock loading. On the one hand, Bailey [5] in England, and Almen and Boegehold [6] in America, hold that a low Izod value is the least of any defects of the steel. Tooth-breakages due to low Izod values alone are non-existent; many gears go into service with Izod values below 10 ft.-lb. but give quite satisfactory "lives" under very heavy shock conditions. On the other hand, McMullan,[7] Rowe [8] and others emphasize the necessity for material of high Izod value to ensure good performance in gears. In order to throw some further light on this problem, and, if necessary, to devise an impact test other than the Izod which would give some indication of the reaction of a gear to shock loading, an investigation was sponsored by the Admiralty-Vickers Gearing Research Association, Sub-Committee "C," and the results are reported below.

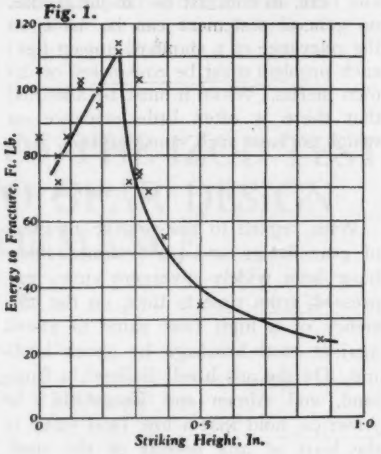
A preliminary examination of the problem showed that the most important design variable influencing the impact value is the ratio of the bending moment to the shear stress across the section of the specimen. An Izod specimen and a gear-tooth are both cantilevers struck at right angles to their length. If the distance from the anvil, or the tooth-root, to the point of application of the blow increases, the bending moment of the applied force increases while the shear stress across the section at any position remains constant. Hence, for a sufficiently long striking distance, the specimen or gear tooth will bend or fracture near the position of fixture, and for a sufficiently short one it will shear off at some position, with probably a very great increase in the energy absorption if the ordinary Izod test is brittle.

A preliminary investigation on Izod tests with variable striking height was made with specimens cut from a carbon-manganese steel forging, normalized and tempered to an ultimate tensile strength of 29 tons per square inch, which was known to have given brittle "crystalline" fractures in the Izod test (24 ft.-lb.). The standard Izod machine was fitted with a striker on the front of the tup in such a manner that the height of the blow above the top of the anvil was adjustable between zero and 1 in. A series of Izod specimens was broken using different striking heights, and the energies to fracture, and the type of fracture were both noted. The results are shown in Table I. Fig. 1, shows the energies plotted against striking height. It will be seen that the energy gradually rises as the striking height falls until a maximum is reached at about ¼ in. striking height; at the same time, the fracture changes from a completely crystalline one to a completely shear one. Below ¼ in. striking height, all the fractures are shear, but the sheared-surface is very curved for the ¼-in. height and this curvature diminishes to almost flat

TABLE I

Height of Striker	Ft./Lb.	Fracture Types
In.		
0.87 (22 mm.) (Standard Izod)	24	Crystalline.
0.50	34	"
0.38	55	Almost all crystalline
0.34	69, 69	Transitional.
0.31	75, 74, 103	"
0.28	72, 72, 72	"
0.25	112, 114	Shear.
0.19	95, 100	"
0.13	103, 101	"
0.09	86	"
0.06	80, 72	"
0	86, 106	"

Fig. 1.

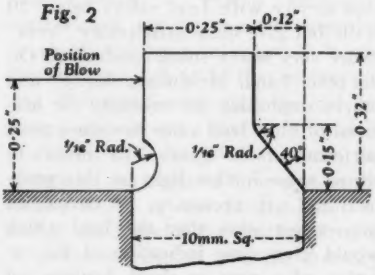


for the lowest striking height. This reduction in curvature, causing a diminution of the actual area of sheared surface, may account for the tendency of the energies to fall as the striking height moves below ¼ in. to zero.

It could be concluded from these results then, that a gear made of material as brittle as the one tested above and with a stress-raiser at the root as drastic as an Izod notch, would give satisfactory performance provided that the striking height of the teeth of the mating gear were less than a certain critical amount, and, indeed, that there is an optimum striking height at which such a tooth would display its toughest behavior.

It was then decided to perform impact tests on a "model" gear tooth, i.e., a type of specimen which would imitate the loading conditions of a typical spur gear tooth, particularly in regard to the stress-concentration factor at the bottom of the tooth and the height of application of the maximum load, but using material of widely different Izod values. After some experimentation with models examined photo-elastically, the specimen shown in Fig 2, was decided upon. Details of the work leading to the choice of this specimen are given in the Appendix to this article. The steels used for the tests were chosen from a series which was being examined by the

Fig. 2



A.V.G.R.A. as possible gear steels. The cast numbers and analyses are given in Table II. They were supplied as 1-in. diameter hot-rolled bar, and the heat-treatment and tensile-test results are shown in Table III. In order to obtain a wide variation of Izod value on these steels, the impact tests were made at different temperatures ranging from room temperature down to — 196 deg. C. (boiling point of liquid nitrogen).

A special pair of Izod anvils was made for these tests, having two bolts joining the two halves so that a specimen can be set up in the anvils away

TABLE II

Steel	Cast No.	Analyses							
		C	Si	Mn	S	P	Ni	Cr	Mo
		Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Med. carbon	30266	0.25	0.16	0.67	0.040	0.036	0.14	0.05	0.03
3½ per cent. nickel	28577	0.34	0.24	0.62	0.060	0.034	3.63	0.12	0.02
En. 19	H.G. 6122	0.38	0.23	0.60	0.016	0.029	0.21	1.09	0.32
En. 29	H.H. 1260	0.21	0.15	0.47	0.016	0.013	0.17	3.09	0.51
En. 30	O.C. 3885	0.30	0.21	0.51	0.011	0.019	4.10	1.17	0.09
En. 36	O.C. 2479	0.13	0.20	0.39	0.030	0.030	3.30	0.85	0.09

TABLE III

Steel	Heat Treatment	Tensile Tests								Izod
		Limit of Proportionality	Proof Stress				Ultimate Tensile Strength	Elongation	Reduction of Area	
			0.05	0.1	0.2	0.5				
		Tons Per Sq. In.	Tons Per Sq. In.	Tons Per Sq. In.	Tons Per Sq. In.	Tons Per Sq. In.	Tons Per Sq. In.	Per Cent.	Per Cent.	Ft.-Lb.
Med. carbon	Normalized 850 deg. C./A.C.*	22		Yield point 22.6			34.6	34.	61.9	56, 60
3½ per cent. nickel	840 deg. C./O.Q.T. 670 deg. C./A.C.	27	33.7	34.4	34.8	35.5	49.8	24.3	47.4	—
En. 19	860 deg. C./O.Q.T. 720 deg. C./A.C.	40		Yield point 41.7			48.2	27.6	67.6	93, 97
En. 29	900 deg. C./O.Q.T. 600 deg. C./A.C.	40	49.0	50.7	52.3	54.5	60.5	21.5	70.9	92, 95
En. 30	820 deg. C./A.C.T. 525 deg. C./A.C.	45	65.5	67.6	69.4	71.0	75.8	17.8	54.4	11, 12
En. 36	860 deg. C./O.Q. 770 deg. C./O.Q.T. 200 deg. C./A.C.	14	34.8	40.5	46.4	54.2	65.4	19.0	60.8	58, 63

* A.C. = air-cooled; O.Q. = oil-quenched; T. = tempered.

from the machine. The specimen and the anvils in which it was gripped were then all lowered into the refrigerating medium and allowed to soak for half an hour. The whole fixture was then lifted out, slid into the machine, tightened, and the specimen broken in about 3 to 4 sec. The refrigerating medium, below 0 deg. C. and down to — 78 deg. C., was solid carbon-dioxide in methylated spirit, and below — 78 deg. C. it was pentane in a special container with a double-walled jacket into which liquid nitrogen could be poured as required in order to attain and hold any particular temperature. Temperatures were measured with a copper-constantan thermocouple which was checked against the freezing point of mercury and the boiling point of liquid nitrogen.

The test results obtained are given in Table IV, and a graph of the results is given in Fig. 3. As with the preliminary series above, the specimen showed variation in the mode of fracture. Although most of the curves show a falling tendency for the special test piece as the Izod drops from high values to low ones, there is no drop of any real significance until about 25 ft.-lb. Izod is reached, when the En. 29 material (3 per cent. Cr Mo) has dropped from about 45 ft.-lb. to 32 ft.-lb. It is only below an Izod of 5 ft.-lb.,

TABLE IV

Temp.	Med. Carbon Steel	
	Special Test Piece	10 mm. Square, Izod
Deg. C.	Ft.-Lb.	Ft.-Lb.
+ 100	65	68
+ 30	66	63
+ 20	60, 60	56, 60
+ 3	69	40
− 10	67	32
− 30	71	27
− 50	62	14
− 77	61	5
− 100	58	5

Temp.	3½ Per Cent. Nickel Steel	
	Special Test Piece	10 mm. Square, Izod
Deg. C.	Ft.-Lb.	Ft.-Lb.
+ 60	67	58
+ 20	67	54, 54
− 50	76	21
− 60	65	35
− 125	65	18
− 150	61, 61	10
− 160	50, 49	10
− 196	53, 35, 66	2

Temp.	En. 19 Steel	
	Special Test Piece	10 mm. Square, Izod
Deg. C.	Ft.-Lb.	Ft.-Lb.
+ 20	58, 68	93, 97
− 25	67	96
− 50	68	95
− 77	62, 62	94
− 95	58	63
− 112	53	40
− 130	53	20
− 150	50	19
− 196	38	5

Temp.	En. 29 Steel	
	Special Test Piece	10 mm. Square, Izod
Deg. C.	Ft.-Lb.	Ft.-Lb.
+ 20	40, 48	92, 95
0	46, 49	96, 100
− 25	42	99, 99
− 100	37, 41	48
− 120	32	37
− 150	27	16
− 196	25, 29	4

Temp.	En. 30 Steel	
	Special Test Piece	10 mm. Square, Izod
Deg. C.	Ft.-Lb.	Ft.-Lb.
+ 100	42	21
+ 20	36	11½, 12
0	37	11
− 42	37	7
− 77	35	6
− 100	31	4

Temp.	En. 36 Steel	
	Special Test Piece	10 mm. Square, Izod
Deg. C.	Ft.-Lb.	Ft.-Lb.
+ 20	49, 67	58, 63
− 40	49, 52	36, 50
− 60	50, 51	29, 41
− 77	47, 53	21, 32
− 100	52, 53	17
− 130	46	17
− 150	36	15
− 196	38, 42	7

however, that the special test shows signs of a drastic fall which might be of serious consequence in service.

Lest it may be thought that the known rise in the strength of steel as the temperature falls may have affected the results favorably where shear processes are concerned, a series of tests was made with a 1 per cent Cr steel of the following analysis: carbon, 0.30; silicon, 0.14; manganese, 0.53; sulphur, 0.025; phosphorus, 0.023; nickel, 0.05; and chromium, 0.97. This was hardened and tempered to an ultimate tensile strength of 50 tons per square inch in bar sizes of 1 1/16 in., 1⅛ in., 2⅛ in., 3 in., 4¼ in., and 5½ in., thus giving a range of Izod values at the same tensile level. Izod specimens, and the special impact specimens were made and broken with the following results:—

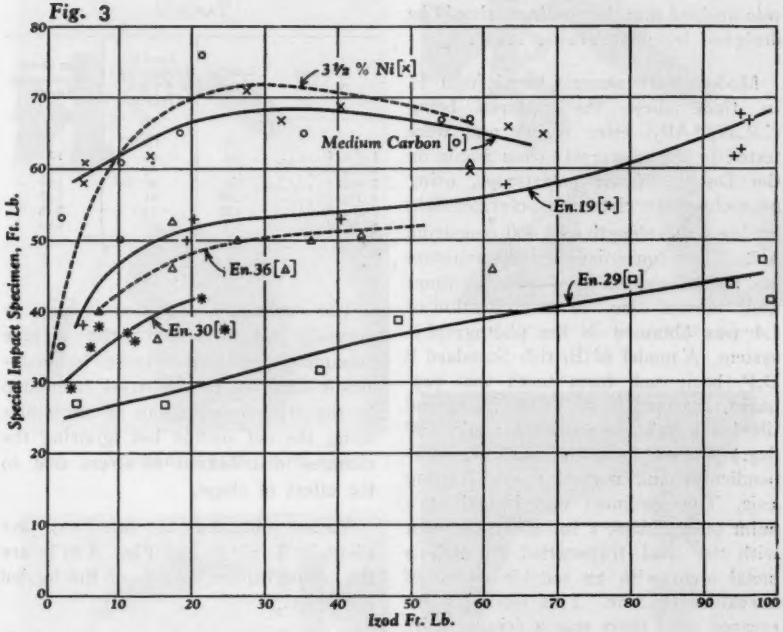
—	Ft.-Lb.	Ft.-Lb.	Ft.-Lb.
Izod	26–32	18–32	54
Special test-piece	55–58	53–58	50–62
Izod	69–88	84–87	95–96
Special test-piece	53–53	63–63	70–76

Again, the general layout of the points is similar to that already obtained by the varying-temperature test.

GENERAL CONCLUSION

It would appear from the above results that there is little value in requiring gear material to have an Izod value in excess of 5 ft.-lb., as far as shock-loading conditions are concerned. On the other hand, as a fair safety margin for very high-duty gears, values of, say, 10 ft.-lb. minimum might reasonably be requested, but this could be justified only for very special examples. In any instance where some doubt may arise as to the suitability of a steel having a low Izod value for the manufacture of a particular gear or set of gears, the authors feel that the special impact test specimen described above would provide a useful guide for the engineers concerned. While the actual energy level

Fig. 3



itself would not be of direct value, the appearance of the fracture—whether brittle or shear—would be sufficient to indicate whether the material would behave in a brittle or a "tough" manner when made into gears.

The authors are indebted to the Council of the Admiralty-Vickers Gearing Research Association, the directors of the English Steel Corporation, Limited, and Messrs. David Brown (Huddersfield), Limited, for their permission to publish the results reported in this article.

APPENDIX

DESIGNING A "GEAR TOOTH" IMPACT SPECIMEN BY PHOTO-ELASTIC STUDY

When this investigation was first opened it was agreed that the gear tooth impact specimen should conform to the following requirements. (a) That the portion of the specimen above the notch should simulate the largest standard tooth form that could be accommodated on a 10-mm. square specimen; (b) that the load should be applied normal to the flank of the "tooth" and at the point which corresponds to that which produces the greatest bending stress in a gear tooth; (c) that the amount of energy required to break the specimen should be within the capacity of the 120 ft.-lb. machine; and (d) that the stress concentration value of the "notch" should be similar to that of the fillet of the equivalent tooth. On account of these special requirements it

was decided that the specimen should be designed by photo-elastic study.

Models were manufactured from ⅛ in. thick sheet, the material being C.R.39 (Allyl ester resin) and were tested in the universal stress frame on the David Brown polariscope, using monochromatic circularly-polarized light having a wavelength of 5,460 Ångström units. For convenience of manufacture and test, all models were made five times their normal size. A magnification of 1.4 was obtained in the photographic system. A model of British Standard 9 D.P. basic-rack form tooth was prepared, mounted in the stress frame and tilted through the pressure angle (20 deg.) so that the loaded flank was perpendicular and normal to the loading axis. The specimen was loaded at a point on the flank 1 in. above the root with the load transmitted through a metal strip with an outside radius of curvature of 5 in. This load was increased until there was a fringe order of two at the tension fillet and a photographic record was taken.

Several specimens, the designs of which were based on the 9 D.P. tooth, were prepared and tested in a similar manner. As before, the load required to produce a fringe order of two on the tension "notch" were noted and photographic records taken of the specimen under load. In order that the stress-concentration factors and load values of these specimens might be compared with those of the standard Izod specimen, models of the latter (× 5 normal size) were prepared and loaded: (a) at normal distance from the notch (corresponding to the normal striking height of the 10-mm. sq. Izod test piece), and (b) 1 in. from the notch (corresponding to a position near to the tip of the hypothetical 9 D.P. tooth the fillet of which was made to blend with the notch).

TABLE V

Specimen Number	Loading Height	Load to Produce Two Fringes (Tension)	True Stress-Concentration Factor
	In.	Lb.	
1 (Fig. 4).....	1.0	63	1.34
2 (Fig. 5).....	1.0	44	1.92
3 (Fig. 6).....	1.0	43	1.97
4 (Fig. 7).....	1.25	43	1.35
5 (Fig. 8).....	4.25	6.2	3.10
6 (Fig. 9).....	1.0	28	2.96

The stress-concentration factor is normally taken as the ratio of true maximum stress as determined by photo-elastic analysis, to the stress calculated by the ordinary equations of mechanics using the net section but ignoring the changed distribution of stress due to the effect of shape.

Values obtained in this way are given in Table V, and Figs. 4 to 9, are the photographic records of the loaded specimens.

Specimen No. 1, shown in Fig. 4, is the model of a 9-D.P. B.S. basic-rack tooth form inclined at an angle of 20

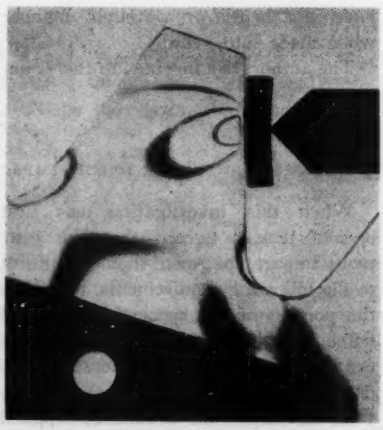


FIG. 4—9 D.P. Basic-Rack Tooth Form.

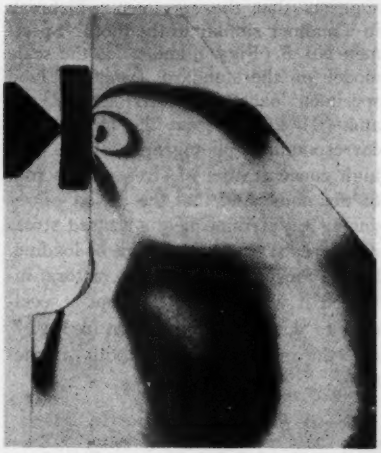


FIG. 5—Modified 9 D.P. Tooth Form.

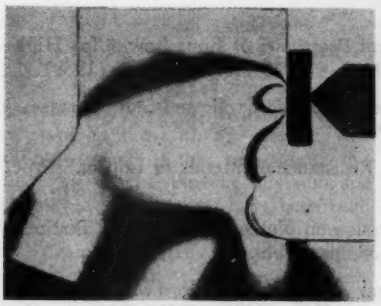


FIG. 6—Tooth Form with Strengthening Pad.

deg. and having the upper portion of the following tooth cut away to facilitate normal loading. Specimen No. 2 (Fig. 5) is the 9-D.P. tooth form modified for the impact specimen. A small projection has been removed from the rear and a little extra left on top. Not only does this increase the stress concentration factor, but practical breaking tests indicate that the specimen is liable to shear at half depth. Specimen No. 3 (Fig. 6) is based on the inclined 9-D.P. tooth form, but a strengthening pad has

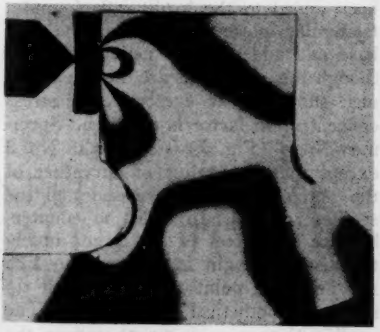


FIG. 7—Tooth Form with Modified Notch.

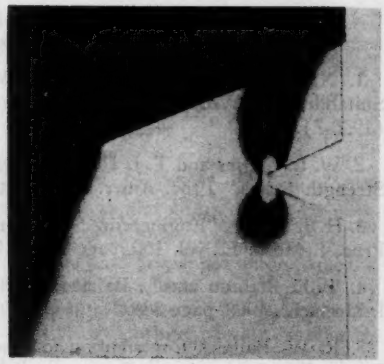


FIG. 8—Standard Izod Specimen.

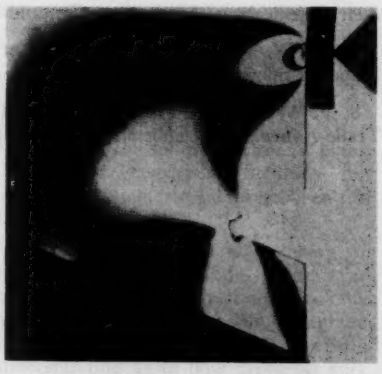


FIG. 9—Standard Izod Specimen.

been added to the loading flank and a triangular piece taken from the rear base and added to the near flank. Although the indications are that the specimen should break correctly, the stress concentration factor is too high. Specimen No. 4 (Fig. 7) is similar to No. 3 except that the radius of curvature of the notch has been increased and the section relieved. In order to counterbalance the effect of the larger notch, the loading height is increased to 1.25 in., i.e., to a point near the tooth tip in the hypothetical gear tooth. The modifications are shown to reduce the stress concentration factor to that of the equivalent tooth and the stress pattern suggests that the specimen will break in a manner similar to the tooth. Specimen No. 5 (Figs. 8 and 9) is the scale model of the standard (square) Izod specimen loaded at points (1) 4.25 in. and (2) 1.0 in. from the notch. The corresponding photograph shows the high concentration of stress at the root of the notch and that the action of reducing the striking height caused stress interference from the point of loading. After consideration of all factors involved it was decided to adopt a specimen to design No. 4, shown in Fig. 7, for the simulated gear-tooth impact tests.

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EXTENDING ENGINEERING SKILLS WITH LARGE-SCALE DIGITAL COMPUTERS

ACKNOWLEDGMENT

MR. ALLEN KELLER, of the General Electric Company, Lynn, Massachusetts, presented this paper at the Management Conference of the American Society of Mechanical Engineers in Detroit, Michigan, in April 1953. The paper was published in the November 1953 issue of "Mechanical Engineering."

INTRODUCTION

For a few years, punched-card machines have been used by several divisions in the author's company for solving various kinds of engineering problems. In the Turbine Division, for example, such machines have been used for calculating critical speeds of shafts, for evaluating stresses, for making theoretical fluid-flow studies, for scheduling drawing-office output, and for some other specialized jobs. Within the past few months, it has become apparent that card-programmed calculators are useful for solving a rather wide variety of such problems.

This paper deals with a different kind of computer, the large-scale computer of the "giant-brain" type in which all instructions as well as data are stored internally. The internal storage of orders gives the computer another degree of freedom in that a large number of different calculation procedures may be stored internally inside the computer and the computer, itself, instructed to select the applicable procedure for each specific calculation.

For several years, the author and his associates have been studying the application of large-scale computers to the solution of turbine design problems. During 1953, a modern, high-speed, high-capacity, electronic computer * will become available for the use of turbine engineers in the author's company. The computer will be located at Evendale, Ohio, in a jet-engine factory. Turbine engineers at Schnectady, N. Y., Lynn, Mass., and Fitchburg, Mass., will use the machine by sending their problems to Evendale for solution. Present plans are to use leased-wire facilities for transmitting numerical data between the different locations.

To most engineers and members of management the claims made for modern computers sound fantastic. This is so because most people, even the otherwise well informed, have little understanding as to how problems may

* IBM-Type 701 Electronic Data Processing Machine.

be set up for solution on an automatic calculator. For example, much engineering data are empirical and expressed in graphical form. Without special input equipment, which is expensive and not generally available, digital computers cannot work with charts. Therefore, the reaction of the average engineer is, "A digital computer cannot possibly solve my problem. My data are mostly empirical and mathematical expressions do not exist for the functional relationships involved."

Much has been written on what computers can do; relatively little has been written on how they do it. The discussion which follows considers one specific repetitive engineering problem and shows how the problem may be organized for automatic computation. Following this, possible computer applications are reviewed and suggestions made for undertaking a study as to the value of automatic calculation in any particular case.

GENERAL DESCRIPTION OF A 1954 OR 1955 MODEL COMPUTER

It requires a year or more to build an organization for using a digital computer. Therefore, anyone not now using such a machine but contemplating the use of one should think in terms of what will be available in 1954 or 1955.

Following the pattern of every new development, early large-scale computers gave rise to the usual trials and tribulations. The time has now been reached, however, when it can be said that computers do, in fact, "compute." Of course, the reliability of different makes of computers varies and the performance of all makes will improve further, but many computers are now establishing records of error-free operation for a large proportion of their scheduled operating time.

In this paper it is assumed that computers are electronically and mechanically reliable. Many 1953 computers are "good" in this respect, and 1954 and 1955 models will be better. This point will not be discussed further.

It has been said that computers have improved 10 to 1 each year for the past few years. This would mean that they are now 1,000,000 times as good as 6 years ago. This may be somewhat of an exaggeration but does illustrate the extremely rapid tempo of new developments in the computing-machine field.

The following is a description of a computer about 10 times as good as present-day models with respect to computing speed and internal storage capacity. This description is given so the reader will have a clear idea of the general type of computer being considered:

1 Form of input and output "words": 10 decimal digits and/or alphabetical characters.

2 Computing speed: 100,000 ten-digit additions or subtractions per second. 20,000 ten-digit multiplications or divisions per second.

3 Internal storage capacity, 10,000 to 20,000 ten-digit numbers. (The program, i.e., sequence of individual operations, for solving a problem is stored internally as well as all numbers used in the problem.)

4 External storage capacity: Unlimited storage in a magnetic-tape library (1,000,000 or more ten-digit numbers available to the computer without human intervention.)

5 Machine errors: About one per billion operations.

6 Probable cost of the 1954 or 1955 model: $200,000 per year rental (including maintenance). $500,000 to $1,000,000 purchase price.

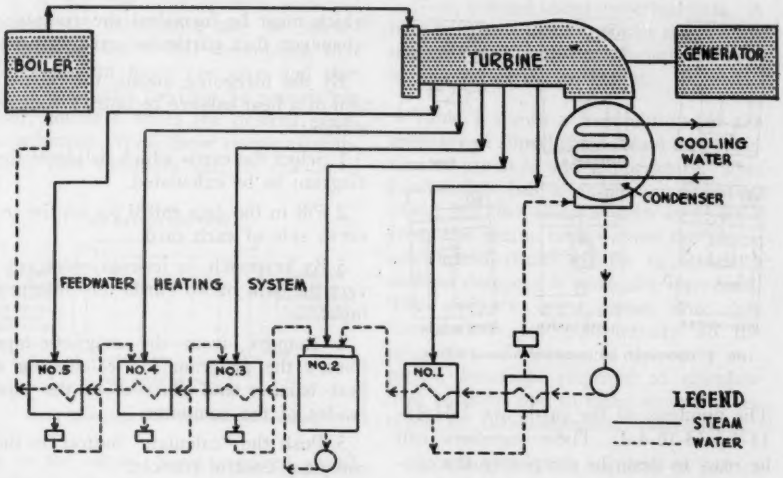


FIG. 1 HEAT-BALANCE DIAGRAM FOR PREFERRED STANDARD TURBINE-GENERATOR SET

TYPICAL ENGINEERING PROBLEM FOR LARGE-SCALE DIGITAL COMPUTER

To illustrate how a complicated problem may be organized for automatic computation, an example has been chosen which will be unfamiliar to many readers. An understanding of the details of the problem is not required, however, to appreciate how it may be solved.

Fig. 1 is a turbine heat-balance diagram. The mathematical problem is to calculate the steam and water flows at all points in the diagram when the generator is delivering a stated electrical output.

For economic and other reasons, a different diagram (number and arrangement of feedwater heaters) is generally specified for each turbine application. In fact, several diagrams are often studied for a single application to determine the most economical and practical arrangement of equipment. A limited number of persons in the author's company are kept busy making these calculations, and many more calculations would be useful if they could be made quickly and inexpensively.

CALCULATION OF A TURBINE HEAT BALANCE ON A DIGITAL COMPUTER

The calculation of a heat balance is generally considered to be a rather involved operation. The solution is a matter of trial and error. Even so, the problem can by systemized until it becomes a routine matter to solve on an automatic computer.

Although all heat-balance diagrams are different, they are all built up from the same standard components. Fig. 2 shows some of these components drawn on individual movable cards.

Fig. 3 shows the cards of Fig. 2 rearranged (and repeated when necessary) to form a picture which is the diagrammatic equivalent of Fig. 1.

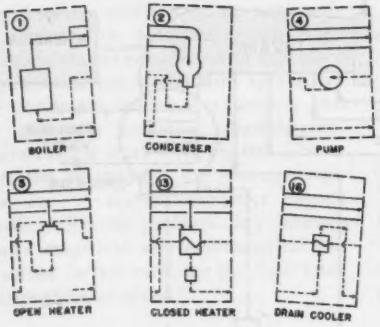


FIG. 2 COMPONENTS OF FEEDWATER-HEATING SYSTEM

The numbers of the cards are 1-13-13-13-4-5-13-16-4-2. These numbers can be used to describe completely the diagram Fig. 1 to an engineer and, by proper programming, can be used to cause an automatic calculator to make calculations for the proper feedwater-heating components.

A survey has shown that with about 50 different kinds of cards, substantially all desired diagrams can be delineated easily and quickly, including the fine points concerning packing, drain piping, feed-pump efficiency, turbine state line shape, and so forth. This method of programming with cards might be called "pictorial programming."

Of course, the input data required for the solution of a particular heat balance will depend on the complexity of the diagram. Each pictorial programming card can have printed on its reverse side precise instructions as to the data which must be furnished the computer whenever that particular card is used.

By the foregoing means, the calculation of a heat balance becomes a routine matter:

1 Select the cards which delineate the diagram to be calculated.

2 Fill in the data called for on the reverse side of each card.

3 By keypunch, or its equivalent, convert the data on all cards into machine input.

4 Remove from the magnetic-tape library the program for calculating a heat balance and place it in the tape reader of the computer.

5 Push the "calculate" button on the computer control console.

After this, complete heat balances for a number of different loads and exhaust pressures should be forthcoming at the rate of one every few seconds. This should constitute an extension of engineering skills.

The foregoing shows how easily new heat-balance diagrams can be programmed for calculation after a suitable subprogram has been prepared and written on magnetic tape. A brief look at the organization of the calculation itself is now in order.

Fig. 4 shows a simplified feedwater-heating diagram. In this figure, all of the thermodynamic medium (steam or water) flows around the outside loop in a clockwise direction except the steam extracted for feedwater heating. An actual diagram is more complicated than

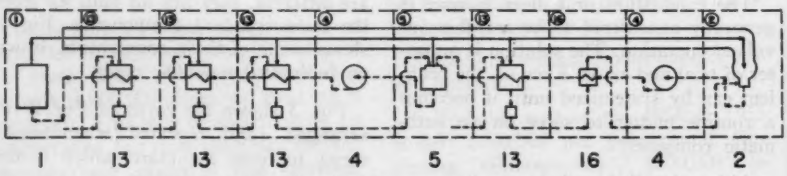


FIG. 3 "PICTORIAL PROGRAM" OF HEAT-BALANCE DIAGRAM OF FIG. 1

Fig. 4, but the same general principle applies. A calculation may be started by making the initial assumption that all extraction flows are zero and that the flow around the loop, in pounds per hour, equals 8 times the desired generator output. With these simple assumptions, first estimates can be calculated

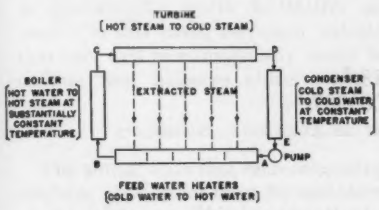


FIG. 4 SIMPLIFIED FEEDWATER-HEATING DIAGRAM

as to the actual flows required at all points in the diagram to generate the desired electrical output. The first estimates will be in error by 10 or 20 per cent in many cases; however, successive iterations of the entire calculation procedure will refine the accuracy of the estimates. After about five complete calculations, all flows will be within 0.01 per cent of their true values for the desired electrical output. With a speed of 20,000 to 100,000 operations per sec, each refinement of the answers will take about 1 sec. On this basis, an engineer cannot afford to spend any time making initial estimates of the extraction flows or even preparing a program for the computer to make good first estimates.

Now, a word about empirical data. A heat-balance calculation will require the use of many empirical functions, such as the properties of steam.

Table 1 shows a formulation for the enthalpy of superheated steam as a function of pressure and temperature. This formulation has a maximum deviation of 0.2 Btu/lb (about 2 parts in 15,000) from the steam table * over the entire superheated-steam region in which a turbine designer is normally interested. The author's organization now has formulations for substantially all the properties of steam and the other empirical functions required to calculate heat balances and to make several other types of thermodynamic calculations.

Supermen are not required to reduce empirical data to equation form, although imagination and originality are big helps. The formulation of Table 1 was derived in about 6 weeks' time by a college instructor ** during summer employment with the author's company in 1952. Only slide rules and desk calculators were available for this work. Other formulations have been derived by half a dozen other people working independently at various times during the past 3 years. None of these persons had degrees above a bachelor's and they used three or four different methods of going about the work. In general, each person used a different technique, but all got results after considerable hard work.

THE GREAT VALUE OF COMPUTERS

From a business standpoint, the heat-balance problem cited can hardly justify $200,000 per year rental for a high-speed computer, although this one problem might justify one from the standpoint of the over-all economy of the country, as will be seen shortly. Several such everyday problems collectively may justify a computer. The big justification for high-speed computers in turbine-design work will come, however, from such things as the improvement of turbine efficiencies by the application of aerodynamic theory to the determination

* "Thermodynamic Properties of Steam," by J. H. Keenan and F. G. Keyes, John Wiley & Sons, Inc., New York, N. Y., 1936.

** Robert M. Jodrey, Instructor, University of New Hampshire, Durham, N. H.

TABLE 1 FORMULATION FOR ENTHALPY OF SUPERHEATED STEAM AS A FUNCTION OF PRESSURE AND TEMPERATURE

$$h = C_0 - C_1 p - C_2 p^2 - C_3 p^3$$

in which:

$$C_0 = 1062.8 + 0.4335t + 0.00003328t^2 + 0.000000003907t^3$$

$$C_1 = \frac{3579}{(t+10)^{1.7036}}$$

$$C_2 = \frac{7{,}774{,}500{,}000}{(t+20)^{5.26158}}$$

$$C_3 = \begin{cases} +\ 0.000002691742 \\ -\ 0.000017295818 \left[\frac{t}{1000}\right] \\ +\ 0.000046260128 \left[\frac{t}{1000}\right]^2 \\ -\ 0.000065814610 \left[\frac{t}{1000}\right]^3 \\ +\ 0.000052468961 \left[\frac{t}{1000}\right]^4 \\ -\ 0.000022206250 \left[\frac{t}{1000}\right]^5 \\ +\ 0.000003895833 \left[\frac{t}{1000}\right]^6 \end{cases}$$

Limits:

$$0 \leqslant p \leqslant 5000$$

$$t_{sat} \leqslant t \leqslant 1200$$

$$1.48 \leqslant s \leqslant 2.50$$

h = specific enthalpy, Btu/lb
p = pressure, psia
t = temperature, F
s = specific entropy, Btu/deg F/lb

of nozzle and bucket blade shapes. One per cent higher efficiency in one year's production of turbines by the author's company will save about $25,000,000 in fuel costs during the life of turbines produced during that single year. If a computer can increase turbine efficiencies by 0.1 per cent per year, then it is economically worth $2,500,000 per year. On this basis, automatic calculation may well be economically sound for turbine heat balances alone, since as little as one or two hundredths of a per cent improvement in power-plant efficiency would save enough fuel to pay the entire cost of operating the computer for a full year.

A modern high-speed computer is costly to operate yet, on large operations, it may easily be worth many times what it costs. In aircraft-design work, for example, a computer may mean the difference between a successful and an unsuccessful plane.

PERSONNEL, THE CRUX OF THE COMPUTING-MACHINE PROBLEM

The author feels that each computing-machine application must be considered as a special case. This is so for the following reasons:

1 To lease or buy computing equipment requires a sizable outlay of money.

2 After a computer is available, each user, for the most part, must develop his own techniques for using the machine. This is true because the entire field of automatic computation is so new and the computing needs of different organizations are so varied that standardized procedures generally are not available at the present time for large problems.

From the foregoing, it is apparent that the crux of the computing-machine problem is personnel. Given a problem large enough to warrant automatic computation, a computing machine in the hands of competent personnel will be a distinct asset; the same machine in the hands of incompetent personnel may be a liability.

The cost of a computing machine itself is a small part of the total cost of making calculations. A machine of the type described in this paper might easily be able to solve as many problems as 50 to 200 or 300 people could program. Even on a highly repetitive job such as heat balances, a good computer, working full time, could make more calculations than a score of engineers could digest. On nonrepetitive work, the ratio of man-hours to machine hours would run much higher.

This brings up the question of the organizational setup for using a computing machine. Two possibilities present themselves:

1 A decentralized setup in which the computer is available to each engineer for solving problems which he himself (with or without the help of assistants) has programmed.

2 A centralized computing group to which engineers bring their problems for solution.

Some persons favor the centralized form of operation, others the decentralized plan. Probably a combination of the two is the best. The author's feeling is that an engineer being pushed for the solution to a problem will take more interest in solving it than will a "professional" calculation group. Therefore, each engineer should be encouraged to program his own problems to the limit of his ability and to supervise the running of his problems on the computer. Many times, however, the mathematics of a problem will be beyond the know-how of an otherwise good engineer. In such cases, a group of numerical analysis specialists should be available to assist in programming the problem or, if it is unusually complicated, to take over the entire job of programming and running the problem. The central group also should lead in the development of

new calculation techniques such, for example, as the development of programs for evaluating the properties of steam, solving differential equations of the types needed in the particular computing-machine application, and so forth.

POSSIBLE APPLICATIONS FOR LARGE-SCALE COMPUTERS

Under this heading may be included just about all big jobs requiring the manipulation of numbers and some problems which a layman would think are not mathematical, such, for example, as the examination of an involved legal document for inconsistencies in the various provisions.

In the author's company, the 701 computer will be used to solve a large variety of engineering problems. These will include the heat-balance problem described in this paper, various kinds of stress and vibration problems, theoretical nozzle and bucket design studies for turbines and compressors, power-plant cycle studies, and many others. In fact, every long or involved calculation procedure, as well as many short but repetitive ones, will be considered as potential problems for automatic computation. The realization of the full potential of a large-scale computer on these problems will take many months or years of developmental effort.

Table 2 lists some of the possible general applications for digital computers and their companion product, record-keeping machines. Record-keeping machines may be used for recording insurance-policy statistics, keeping magazine-subscription lists up to date, recording social-security data, and so forth. They are distinguished from calculating machines in that they are designed for large amounts of input, output, and storage with relatively little calculating while calculating machines are designed for smaller amounts of input and output but larger amounts of computing.

Is the reader's own particular interest listed in Table 2? If not, should it be? To answer this last question is the purpose of the last section of this paper.

The author knows of no better way to determine whether a computer would be economical in a particular case than to ask a long series of questions which should be answered:

1 Consider the calculation (or record-keeping) problem itself.

Is it large or small? If it is small and present methods are giving satisfactory results, automatic calculation probably will not be profitable.

How might machine calculation pay for itself? By solving a wider variety of problems than are now being solved? By making a larger volume of calculations? By completing calculations at an earlier date? By decreasing computation costs? By giving more decimal digits of accuracy? By decreasing numerical errors and procedural errors?

How will the foregoing be converted into profit dollars in the profit and loss statement? By improving the product and reducing complaint expenses? By decreasing the cost of the product? By better customer service and increased sales? By speeding up developmental work through using calculated values instead of engineering estimates in design work? By applying design theories which are not practical without automatic computation?

2 Consider how the problem can be organized for automatic computation.

What will the input quantities be? At what point will the computer start the problem? Where will it end?

Is the problem now organized for automatic computation? If not, who will organize it? How much judgment enters the present procedures? How can this judgment be formulated for an automatic calculator? How often do existing empirical functions have to be extrapolated?

TABLE 2—POSSIBLE USES FOR DIGITAL COMPUTERS AND RECORD-KEEPING MACHINES

1	Small, medium, and large repetitive engineering calculations.
2	Special engineering and scientific calculations.
3	The preparation of handbook data.
4	Data reduction (correcting test data to standard conditions and the interpretation of results).
5	Automatic reading, recording, and reduction of test data. (Systems are now being developed for feeding test values directly into computers, without human observers.)
6	System analyses (for example, determination of optimum compressor pressure ratio for jet engine).
7	Weight control in aircraft design.
8	Statistical studies.
9	Traffic control in cities (which streets should be one-way?).
10	Highway planning.
11	Indexing library data for ready reference. (For example, a comprehensive index of all technical information on computers and their associated mathematics.)
12	Computation and preparation for mailing of telephone and electric bills.
13	Magazine-subscription fulfillment.
14	Home-office records of insurance-policy data.
15	Meteorological predictions.
16	Inventory control (nuts and bolts requirements).
17	Production control (what to manufacture, and when, to meet a frequently changing production schedule).
18	Piecework pricesetting.
19	Manufacturing cost estimates (for special products built largely from standard components, such as many industrial products).
20	Economic studies.
21	Management reports (reports the first day of each month for preceding month).
22	Payroll compilation and check-writing.
23	Veterans Administration records.
24	Social-security records.
25	Bank records and clearance of checks.
26	Centralized control of transportation reservations.
27	Truth analyses. (Are there any inconsistencies in an involved legal document? Someday, a computer may win a law suit.)
28	Manufacturing operations-scheduling (consolidation of different lots in a job-shop type of manufacturing operation to minimize set-up costs and increase output).
29	Medical research and statistical studies.
30	Personnel records.
31	Automatic control of machine-tool operations.
32	Business forecasts and preparation of budgets. (One or more computers predicted the outcome of the recent national election at an early hour, but some persons were skeptical of the predictions.)
33	Scheduling the manpower and output for an operation. (A drawing office for example.)
34	Planning military operations.
35	Planning industrial production during national emergencies. (Remember CMP of World War II. This is a natural for a CoMPuter, both for a large manufacturer and for the Government.)

3 Consider the mathematical tools for solving the problem.

Do known methods of numerical solution exist within the reader's organization? If not, what is the likelihood that they exist elsewhere? Is it likely that new methods can be developed at reasonable cost? What is the source of personnel to do this work?

4 Consider the personnel required to carry out items (2) and (3).

Will the calculations use repetitive or nonrepetitive procedures? How much and what kind of personnel will be required? Is the required personnel already in the organization or will it be necessary to hire outside talent? If new talent is needed, is it available at reasonable salaries? What will be the total cost of personnel? Is floor space available for the machine and the needed personnel?

5 Consider the kind of computer required to do the job. Will a small, medium, or a large computer be required? Talk with different computer manufacturers' sales engineers. Which make of computer has design and operating characteristics best suited to the particular job? What is the expected reliability of the machine that appears best suited for the job? Does outright purchase or rental seem most attractive? Who will maintain the machine? What will maintenance cost?

6 Make an economic appraisal of the entire proposal.

List the results which automatic calculation will be likely to accomplish. Review the means by which competent personnel will be obtained. Review the probable cost of the computing machine together with its associated personnel.

Set down the accomplishments and shortcomings of present methods. Tabulate the costs of present methods.

7 Make a descision based on a combined consideration of items (1) through (6).

SUGGESTIONS FOR MAKING A STUDY TO DETERMINE WHETHER A DIGITAL COMPUTER WOULD BE ECONOMICAL FOR THE READER'S ORGANIZATION

Digital computers are available in a large range of sizes to suit various problems and pocketbooks. For $10,000 to $25,000 yearly rental, punched-card machines may be leased which will solve a wide variety of simple problems and many rather complex ones. Electronic computers with magnetic-drum storage (or its equivalent) may be purchased for approximately $40,000 to $50,000 and up. At the present time, several makes of computers are available with approximately one tenth the speed and one tenth the internal storage capacity of the 1954 or 1955 model imagined by the author. These present-day machines lease for about $200,000 per year or may be purchased for half a million to a million dollars.

CONCLUSIONS

A tremendous amount of effort is going into the automatic-calculator field and many of the latest developments have the financial backing of old and well-established companies. It now appears that computers can, in fact, "compute" and that a large number of new applications will appear in the near future. Alert members of engineering management will watch these developments very closely and many will soon decide, just as others already have decided, that the present is none too soon to prepare to use these very powerful new tools because "computers can extend engineering skills."

TRICKY PROBLEMS IN WELDED SHIP REPAIR

ACKNOWLEDGMENT

This article was presented at the National Spring Meeting of the American Welding Society in Houston, Texas, in June 1953. It was published in the August 1953 edition of "The Welding Journal." The author is MR. MILTON FORMAN, Welding Metallurgical Engineer of the Brooklyn and Hoboken Divisions of the Todd Shipyards Corp.

In its fundamental principles the ship repair business is very much like all others. However, it does have some special features which make it different and which tend to intensify the problems usually encountered. Because a ship is taken out of active service in order to be repaired, there is a tremendous amount of pressure on the shipyard to make the repairs as rapidly as possible. Furthermore, many ship repair jobs are of an emergency nature, with the full extent of the repairs being determined only after the ship has been brought into the yard.

The very character of the work involved is spasmodic. Therefore it is extremely difficult for a shipyard to maintain a stable labor force that will permit the best continuity in work. Within the limitations of these two factors—the necessity for rapid turnaround and the problem of adequate qualified labor—the ship repair yard must gear itself to practices and operations which will assure the highest quality workmanship in the shortest possible time.

In order to achieve this result the usual methods of doing a job are not adequate. Better planning is of the utmost importance. The best type education of supervision and workmen is necessary in order that the best results may be achieved. The greatest ingenuity and initiative are required if the intricate problems of ship repair are to be solved.

SHIP REPAIRS DIFFERENT FROM NEW CONSTRUCTION

In new construction very difficult welding problems face the shipyard. In many cases they are satisfactorily solved. In ship repair all welding problems become more difficult of solution. When building a new ship, relative freedom exists for welding contraction to take place. In the repair of a ship the work is always done in an existing rigid structure. And since welding is always accompanied by shrinking and contraction the resultant problems are multiplied. In other words if welding is done to repair a deck, the deck itself will be put in tension while the attaching shell and bulkheads will be put in compression. The result can be distortion or fracture.

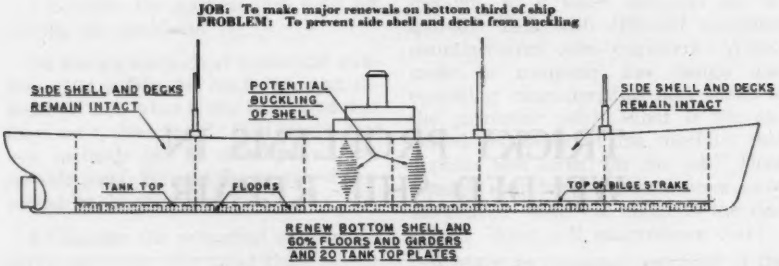

JOB: To make major renewals on bottom third of ship
PROBLEM: To prevent side shell and decks from buckling
SIDE SHELL AND DECKS REMAIN INTACT
POTENTIAL BUCKLING OF SHELL
SIDE SHELL AND DECKS REMAIN INTACT
TANK TOP
FLOORS
TOP OF BILGE STRAKE
RENEW BOTTOM SHELL AND 60% FLOORS AND GIRDERS AND 20 TANK TOP PLATES

Fig. 1 Bottom damage renewals on cargo ship

MAJOR SHELL BOTTOM RENEWAL

Figure 1 represents a typical example of major repairs which must be made on a ship. In this example the entire bottom of the hull has been damaged. The entire bottom shell, 60% of the inner bottom floors and girders and 20 tank top plates must be renewed. Assuming for a moment that the ship is a box girder, it will be noted that the bottom flange may be put in tension as a result of the renewals, the side shell is placed in compression and can develop buckling.

It has been reported by the American Bureau of Shipping that a number of this type of repairs have been made. It is further reported that invariably the side shell buckles. This buckling occurs either immediately upon the completion of the job or within a few months after the ship has been in service.

The Brooklyn Division of Todd Shipyards Corp. was given such a job. After representatives of the American Bureau of Shipping had alerted the yard as to the fate of most of these ships, a care-

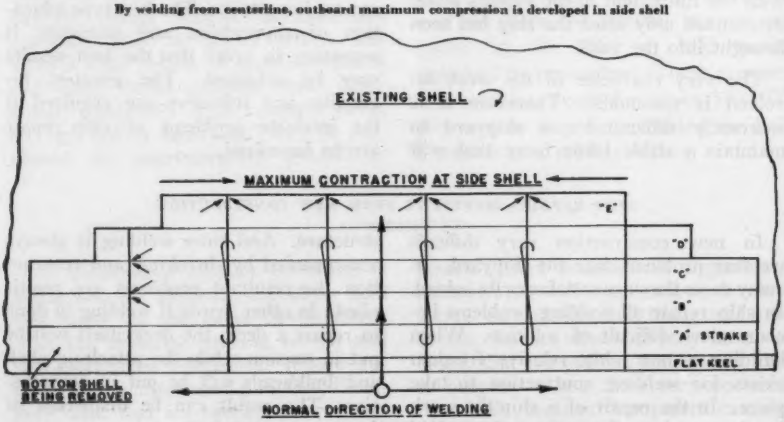


Fig. 2 Pattern of cumulative contraction on bottom-shell repair

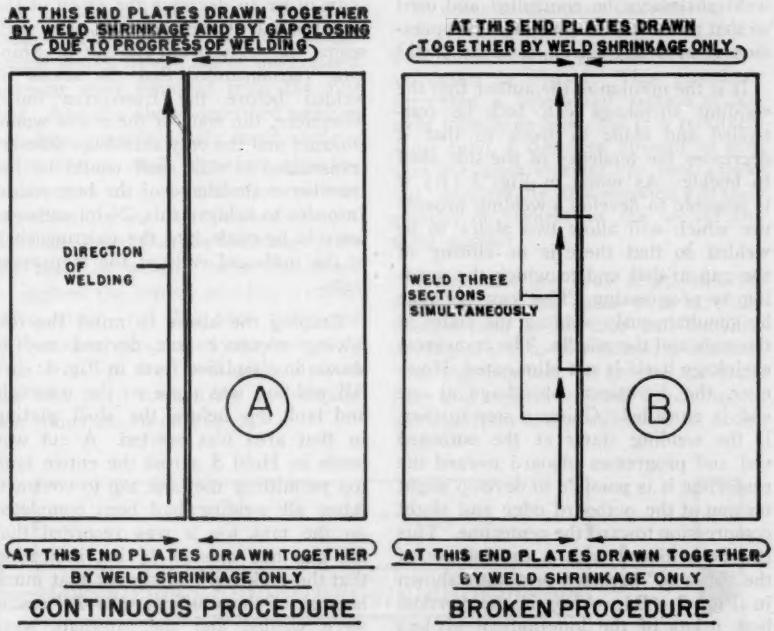

AT THIS END PLATES DRAWN TOGETHER BY WELD SHRINKAGE AND BY GAP CLOSING DUE TO PROGRESS OF WELDING
DIRECTION OF WELDING
A
AT THIS END PLATES DRAWN TOGETHER BY WELD SHRINKAGE ONLY
CONTINUOUS PROCEDURE
AT THIS END PLATES DRAWN TOGETHER BY WELD SHRINKAGE ONLY
WELD THREE SECTIONS SIMULTANEOUSLY
B
AT THIS END PLATES DRAWN TOGETHER BY WELD SHRINKAGE ONLY
BROKEN PROCEDURE

Fig. 3 Procedure to equalize shrinkage in welding along butt joint

ful analysis was made before work was undertaken. First, the traditional sequence of welding was scrutinized. And Fig. 2 shows the pattern of cumulative contraction developed on the bottom shell. The standard sequence usually calls for all welding to start at midships and the centerline and progress fore and aft and outboard, attaching the new bottom plating to the side shell last. It will be noted as shown in Fig. 3 (A) that when welding starts at one end of the plate and progresses toward the other end, two types of movement occur. There is transverse shrinkage across the weld which pulls the two plates together. In addition the end toward which the welding is progressing shows greater movement and the gap closes even more. This is an often observed phenomenon, especially when heavy plates are welded. Therefore at the point where the new plating is to be attached to the side shell there is a cumulation of shrinkage from the many butt welds that is far greater than the transverse shrinkage of the weld itself.

In addition the longitudinal seams joining the bottom shell to the side shell are welded after the transverse welds are made, thereby causing added shrinkage stresses at that point. Also the longitudinal shrinkage of the other seams of the bottom shell act in a manner to tend to raise the keel. It is therefore logical to expect that the side shell immediately above the bilge strake would be put in considerable compression, thereby causing it to buckle. The problem therefore is: Can the normal

weld shrinkage be controlled and used so that an excessive amount of compression is kept away from the side shell?

It is the opinion of the author that the welding shrinkage can both be controlled and made to work so that it decreases the tendency of the side shell to buckle. As noted in Fig. 3 (B) it is possible to develop a welding procedure which will allow two plates to be welded so that there is no closing of the gap at that end to which the welding is progressing. This can be done by simultaneously welding the plates at the ends and the middle. The transverse shrinkage itself is not eliminated. However, the directional shrinkage at one end is curtailed. Going a step further, if the welding starts at the outboard end and progresses inboard toward the centerline it is possible to develop slight tension at the outboard edge and slight compression toward the centerline. This can be achieved with a careful use of the "broken," backstep procedure shown in Fig. 3 (B). Also, if the vertical butt joints of the longitudinal girders are welded, starting at the tank top and progressing toward the shell, a tendency toward tension can be developed at the tank top.

In order to decrease the effect of the longitudinal shrinkage of the shell seams, the American Bureau of Shipping recommended that the seams be welded before the transverse butts. Therefore, the ends of the seams would contract and the only shrinkage stresses transmitted to side shell would be the transverse shrinkage of the butt welds. In order to achieve this, 24-in. cutbacks were to be made into the existing shell at the outboard ends of the transverse butts.

Keeping the above in mind the following sequence was devised and is shown in simplified form in Fig. 4: (a) All welding was done on the internals and tank top before the shell plating in that area was erected. A cut was made in Hold 3 across the entire tank top permitting the tank top to contract. After all welding had been completed on the tank top it was recorded that the gap had opened ½ in., indicating that the tank top had shrunk that much because of the welding. (b) All seams were welded and the internals were welded to the shell between the transverse girth joints. The seams were first welded to the side shell and the flat keel, with the result that the final erec-

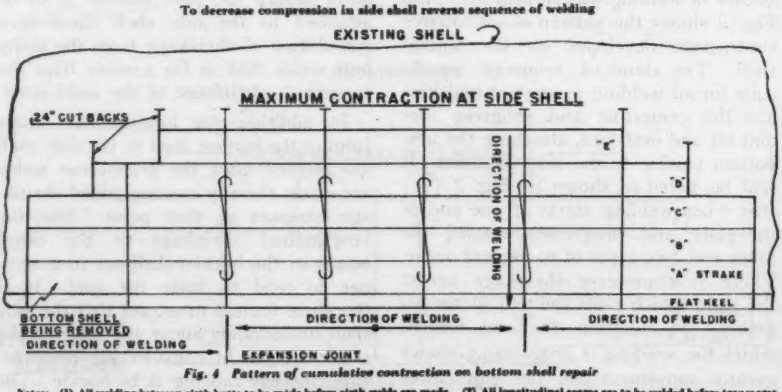


Fig. 4 Pattern of cumulative contraction on bottom shell repair

Notes: (1) All welding between girth butts to be made before girth welds are made. (2) All longitudinal seams are to be welded before transverse welds

tion joint was between the C and D strakes. This meant that the longitudinal seams welded under the greatest restraint were removed from the side shell. Also the above-described welding was done simultaneously in all sections of the bottom shell, therefore allowing a maximum of men on the job without overcrowding in any particular area. It will be noted that the shrinkage from this mass of welding was distributed throughout the bottom avoiding a cumulative effect. (c) The final transverse butt welding progressed simultaneously from midships fore and aft and from bow and stern toward the two expansion joints shown on Fig. 4.

In order to eliminate the tendency for root cracking in the butt joints a modified block welding procedure was used as shown in Fig. 5. This procedure permitted a substantial section of the weld joint to be deposited in a relatively short time, a sufficient amount to prevent the often encountered root cracking. Incidentally, this supplied a certain amount of preheat for the second and third passes.

When this job was completed, the side shell and the decks were carefully checked and in no case had buckling developed due to this extensive welding. The ship has been in service for some time and reports indicate no change in the condition of the side shell or decks.

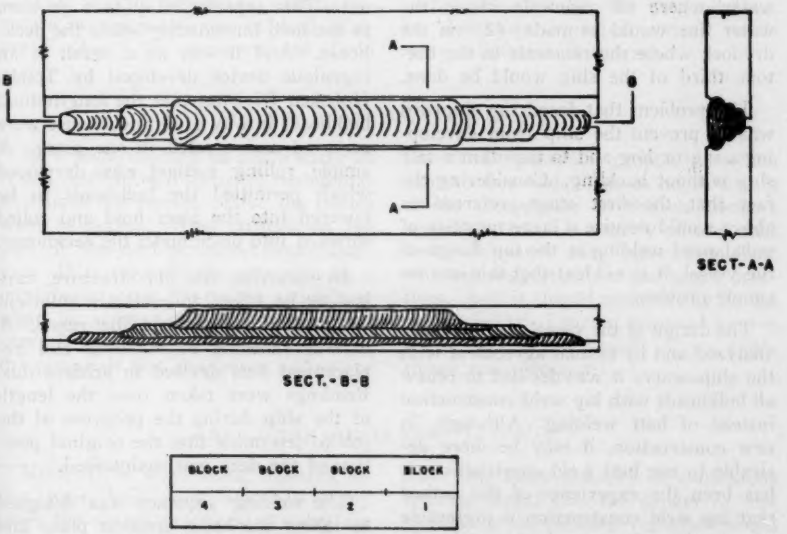


Fig. 5 Modified block weld procedure

RENEWAL OF ALL INTERNALS ON TANKER

The Hoboken Division of Todd Shipyards Corp. was given the job of renewing practically all the corroded internal members of a large tanker. As shown in Fig. 6, this included the main longitudinal bulkheads, the transverse bulkheads, the web frames, centerline girders and the majority of the longi-

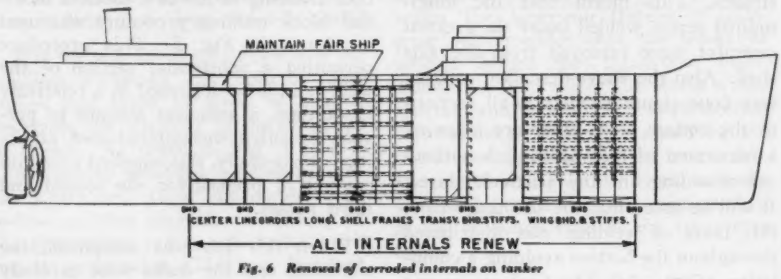

JOB: Renew all bulkheads, transverse webs, longitudinals on deck and shell and centerline girders
PROBLEM: To keep remaining decks and shell from buckling and maintain fair ship
MAINTAIN FAIR SHIP
CENTER LINE GIRDERS
LONG'L SHELL FRAMES
TRANSV. BHD. STIFFS.
WING BHD. & STIFFS.
ALL INTERNALS RENEW

Fig. 6 Renewal of corroded internals on tanker

tudinal framing. For all practical purposes everything was renewed except the shell and deck. This job was to be done in two major stages: (1) In the water where all renewals above the water line would be made; (2) on the drydock where the renewals in the bottom third of the ship would be done.

The problem that faced the shipyard was to prevent the ship from developing a sag or hog and to maintain a fair ship without buckling. Considering the fact that the first stage referred to above would require a large quantity of unbalanced welding at the top flange of the vessel, it is evident that this was no simple problem.

The design of the vessel was carefully analyzed and by mutual agreement with the shipowners it was decided to renew all bulkheads with lap weld construction instead of butt welding. Although, in new construction, it may be more desirable to use butt weld construction, it has been the experience of the author that lap weld construction is preferable when making large scale renewals. In addition to making it easier to erect and fit large assemblies into an existing ship, the shrinkage from welding lap joints is much less than from welding butts.

The deck plates immediately above the longitudinal bulkheads were removed in order to facilitate the removal of the old bulkheads and the erection of large bulkhead assemblies. In fact the basic principle of erecting large preassembled sections was used throughout. This represented quite a problem in the hold immediately below the deckhouse. And it was as a result of an ingenious device developed by Todd's Hoboken Division that the longitudinal bulkheads in way of this deckhouse were removed and erected in one piece. A simple rolling method was developed which permitted the bulkheads to be lowered into the after hold and rolled forward into place under the deckhouse.

In removing the old structure, care had to be taken to maintain sufficient longitudinal strength in the vessel. A careful schedule of removal and replacement was devised to achieve this. Readings were taken over the length of the ship during the progress of the job to determine that the original position of the deck was maintained.

The welding sequence was designed to follow the basic erection plans and certain lap joints on the longitudinal bulkheads were left free to allow for weld shrinkage. It was observed that this shrinkage took place and periodically the tack welds would break at these expansion joints. In order to develop a tendency of tension at the main deck and compression below, all vertical welding started at the top deck and pro-

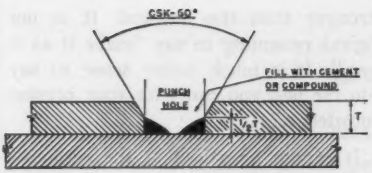


Fig. 7 Recommended detail for plug welding

gressed toward the keel using the back-step method.

At the start of the job the size of the required welds was carefully reviewed and, making sure that they fulfilled ABS requirements, the welding was kept to a minimum. In all cases, despite different original opinions, the shipowner cooperated fully in helping to decrease the amount of welding. In another case the amount of welding required in plug welds was reduced. Figure 7 shows the recommended Todd practice for welding plugs. The reduction of the quantity of welding, although great, is secondary. What is more important is that the quality of the plug joint is assured. The hole shown in Fig. 7 is filled up only after the adjacent tank has been tested. The quality of the weld itself is easily inspected and faulty work, so usual in plug welding, is eliminated.

Even though the American Bureau of Shipping and the shipowner had inspectors on the job, the yard set up its own simple but thorough inspection system. This resulted in practically no pick-up welding being found by the outside inspectors.

Because of careful planning and control, the work on this ship was completed economically and in good time, no distortion developed and all hands were satisfied with the job.

GIVE THE OWNER WHAT HE WANTS?

At a local meeting of the Society of Naval Architects, a shipyard representative made the remark "Give the owner what he wants." This attitude on the part of shipyard personnel bears analysis. It is undoubtedly true that in a most basic sense the owner should get what he wants—a sound ship. However, it is not always true that all of the proposals that the owner makes are the best possible proposals which achieve this end. This is no reflection on the competence of the shipowner's representatives. It merely means that some shipyards may have specialists who can suggest newer and better practices. And it should undoubtedly be the responsibility of such a shipyard to give the shipowner the benefit of its experience and personnel.

SHOULD THE SHIP BE KEPT "AS IT WAS"?

Most of the ships being repaired today were built long ago. In many cases the design practices of today are superior to those of the past. And the question arises whether the repairs should be made according to the old design or according to newer and better practices. With reference to the bottom shell renewal job previously mentioned, the original ship had been welded continuous throughout. To replace this large quantity of continuous welding meant that the danger of distortions on the existing, rigid hull would be increased. The shipowner was quickly convinced that he would get a better job, a fairer ship, with the use of intermittent welding on the internal members.

In another case of an old ship the inner bottom floors were attached to the shell with an angle as shown in Fig. 8.

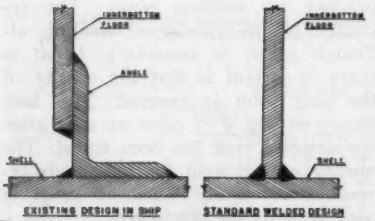


Fig. 8 Should renewals be made to conform to outmoded designs?

Would it not be a more efficient joint to replace the floors to be renewed with a joint as shown on the right-hand side of Fig. 8? This would result in less welding, less weight, greater strength and higher quality of welding. And despite the fact that some floors would have a slightly different joint detail, the ship itself would be as strong or stronger than the original. It is not logical reasoning to say "make it as it was." It is much better sense to say "do the best you can with your present knowledge."

It cannot be said that the responsibility for the use of outmoded designs and practices is in the hands of the owners or inspectors alone. Experience has proved that the shipowners, the American Bureau of Shipping and other regulatory bodies, as well as the shipyards, are eager to cooperate when sound suggestions are made which improve the work. What is required is an alertness on the part of qualified personnel toward making improvements, and a determined desire to avoid the line of least resistence—"give the owner what he wants."

MAKING A FETISH OF WELDING SEQUENCE

Although the experience of World War II should have been ample proof that there is more than one way to weld a job, hangovers still exist that *one welding sequence can be the best welding sequence.* As long as the welding sequence fits into the larger picture of the basic fabrication and erection plan of a given yard it can be made to be satisfactory. Yet it still happens that a contract is written which dictates a basic aspect of a welding sequence. An example of this can be cited when recently some barges were to be built. In this case the contract read that all welding was to be completed within any girth section (as shown on Fig. 9) before the transverse girth joints could be welded. In addition it was specified that the deck bottom shell and side shell must be welded simultaneously. An examination of Fig. 9 makes it quickly evident that any number of satisfactory welding sequences could be devised to properly weld such a simple structure. For example: The bottom shell could be welded together in whole or in part; the side shell and deck could be welded in similar fashion and then all these could be joined together with the proviso that no unwelded butts be crossed and that the welding proceed on port and starboard sides simultaneously. If the erection and fitting proceeded according to the original schedule no changes in any given sequence would be required. However, if changes in the erection were necessitated, then the welding sequence could be easily changed to suit. The main point is that there is no justification for limiting any shipyard to a preconceived welding sequence.

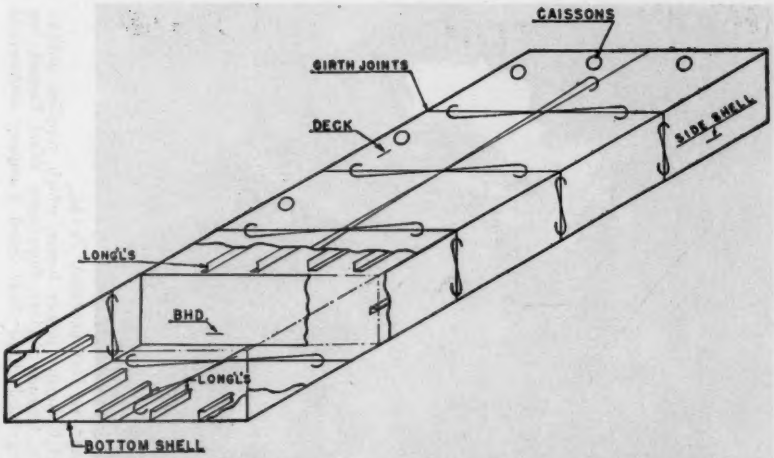


Fig. 9 Hypothetical barge showing many possible welding sequences

Note: **Any number of satisfactory welding sequences can be developed to weld this structure**

WORKMANSHIP

There is prevalent a false opinion that once the inspection agencies pass a job, the shipyard is relieved of responsibility. Most important, the yard has the responsibility of protecting its reputation. Some people have expressed the opinion that a ship repair yard ought to "guarantee" its welding by the use of Radiographic Inspection. If this becomes standard practice, the shipowners will in the long run have to pay for this additional inspection device. The only way to save the shipowners this expense is for the ship repair yards to develop methods, procedures and control *in the process of doing the job* which prevents any one from casting any reflection on the quality of their work. This is not an impossible job. On the contrary, it is very desirable under any conditions.

Welding has proved itself a thousand times in the construction of new structures. It has permitted better designs, more economical and stronger ships to be built. The repair of these vessels has followed in the same tradition and as time goes on even greater progress will be made.

OVERALL VIEW OF THE NAVY ORDNANCE AEROPHYSICS LABORATORY, DAINGERFIELD, TEXAS

In the background is 1,500 acre lake Ellison; at right is Lone Star Steel Company power house, which supplies utilities and air to the Ordnance Aerophysics Laboratory. Center of picture shows High Altitude Facility, Supersonic Wind Tunnel, Sea Level Propulsion Laboratory, Office Building and supporting facilities. Foreground—Lone Star Steel Company commercial operations.

EXHIBIT 1

A GUIDED MISSILE INCUBATOR

LIEUTENANT THOMAS K. EWAN, USNR

THE AUTHOR

is Assistant Inspector of Naval Material, Daingerfield, Texas, serves on the staff of the Supervising Inspector of Naval Material, Houston, Texas, for administration and as the authorized representative of The Chief of the Bureau of Ordnance for operation of the Naval Ordnance Aerophysics Laboratory, Daingerfield, Texas, and the Defense Research Laboratory of the University of Texas. In addition to an extended period in Naval research and development in torpedo exploder mechanisms and in guided missiles, he has served both as a Reserve Officer and in a civilian capacity. The author is also Commanding Officer of the Naval Reserve Ordnance Company 8-1.

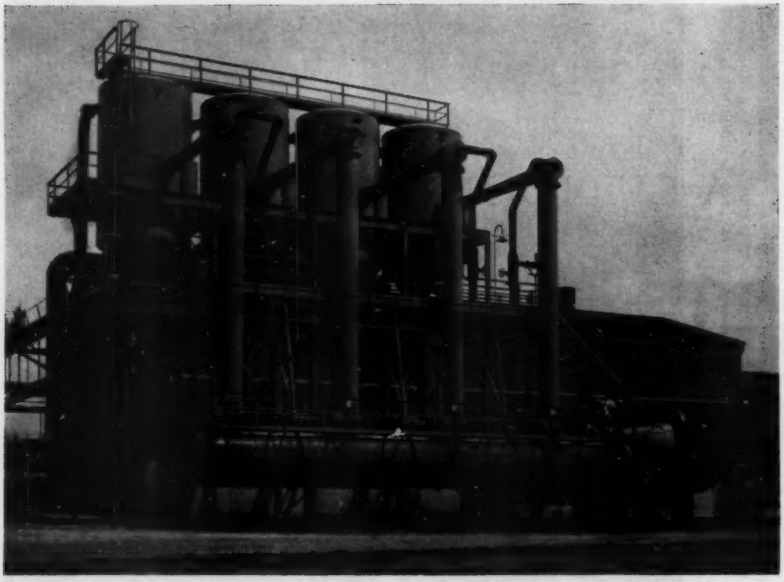
Nestled in the piney woods of Northeast Texas is a research tool of a Nationwide Network of sixty university and industrial contractors of the Armed Services of the Department of Defense —The Naval Ordnance Aerophysics Laboratory (Exhibit 1)—It is a guided missile incubator. This little publicized research and development facility is engaged in guided missile development and testing serving the National Military Establishment including contractors of the Army, Navy and Air Force. It is a prime example of unification of the Military services at work.

The Ordnance Aerophysics Laboratory is totally Navy-owned and is operated for the Navy's Bureau of Ordnance by an industrial organization, Consolidated Vultee Aircraft Corporation. The same industrial organization has operated this laboratory since its inception under a cost-plus-fixed-fee research and development contract.

The Ordnance Aerophysics Laboratory was first established to carry out research and development test programs for the Section "T"[1] family of contractors. Technical guidance for the Ordnance Aerophysics Laboratory is furnished by the Applied Physics Laboratory of The Johns Hopkins University operating under a separate prime contract with the Bureau of Ordnance of the Navy. The Section "T" Bumblebee Missile Program utilizes approximately 60 percent of the available wind tunnel test time and approximately 20 percent of the available propulsion test time of the Ordnance Aerophysics Laboratory. Other available test time is utilized by other guided missile contractors of the Armed Services. Representatives of the Military Services and civilian organizations, including both university and industrial personnel, form panels allocating available test time on a need basis rather than on a service-affiliation basis.

EXHIBIT 1

Level Propulsion Laboratory, Office Building and supporting facilities. Foreground Zone Ball Steel Company operations.



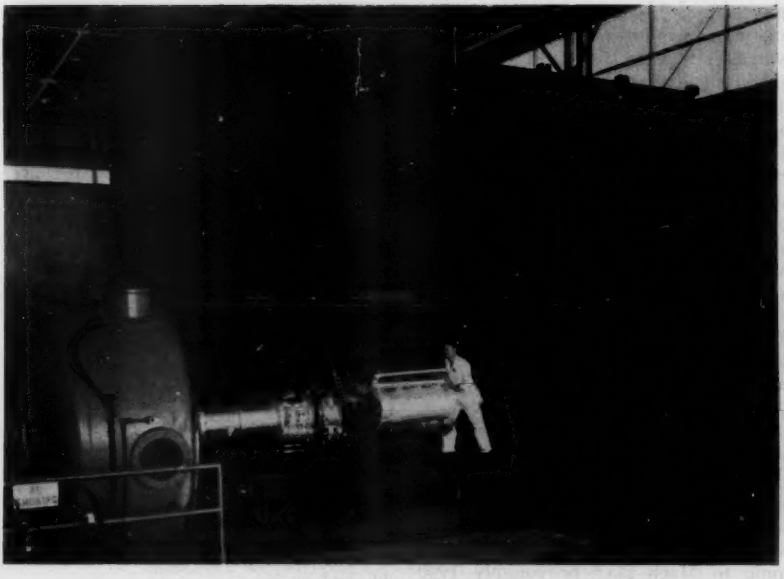
EXTERIOR VIEW OF THE ORDNANCE AEROPHYSICS LABORATORY
HIGH ALTITUDE RAMJET TESTING FACILITY

Top of picture shows steam-jet ejectors and barometric condensers. These constitute part of the vacuum system to lower pressure and simulate high altitude conditions. The cylinder running along the ground is a portion of the test chamber.

EXHIBIT 2

The site for the Ordnance Aerophysics Laboratory was selected in 1945 in an idle blast furnace plant because of availability of steam, water, electricity, rail and other services necessary for a laboratory of this type. The Ordnance Aerophysics Laboratory is located on 23 acres of Government owned land adjoining a 1,500 acre lake. The Lone Star Steel Company, also operating under a direct prime contract with the Bureau of Ordnance, furnishes the utility services necessary for the operation of the laboratory—water, electrical power, steam, railroad facilities, and related services.

The work of the laboratory is divided into two principal functions, a propulsion laboratory and a supersonic wind tunnel. The propulsion laboratory is primarily engaged in the testing and development of supersonic ram-jet power plants for guided missiles.[2] This propulsion laboratory has four (4) ram-jet engine test cells consisting of a high altitude chamber (Exhibit 2), two permanent indoor sea-level cells, and one outdoor sea-level cell. The high altitude chamber was placed in operation early in 1950. This facility has the capacity to test missiles up to altitudes of 100,000 feet at speeds four times the



A VIEW OF THE INTERIOR OF THE HIGH ALTITUDE FACILITY OF THE ORDNANCE AEROPHYSICS LABORATORY

A ramjet test type engine being installed for a test run. The large door shown in top of picture closes. Engines may be tested in the chamber at simulated altitudes of 20 miles above the earth.

EXHIBIT 3

speed of sound. Testing of ram-jet engines in the high altitude facility takes place in a 10 foot diameter cylindrical chamber (Exhibit 3) 125 feet in length with a 30 foot long door in its side through which ram-jet engines are installed for tests. The simulation of high altitudes throughout the normal operating range of ram-jet engines is made possible by the combination of a high pressure air supply system combined with a vacuum system. The vacuum system combines steam jet ejectors for first stage evacuation and turbo blowers for second stage evacuation obtaining the maximum capacity from a steam supply of 270,000 pounds per hour of 700°F steam at 400 pounds per square inch pressure. By way of comparison, this amount of steam, if used for the generation of electrical energy, would supply electricity for a city of 100,000 persons. A cooling system provides 30,000 gallons of water per minute to a ram-jet exhaust cooling chamber and to barometric condensers located between the ejectors and blowers. This water is divided as follows: 20,000 gallons of water per minute for the barometric condensers are pumped from a 3,000,000 gallon cooling reservoir. The 10,000 gallons of water for exhaust cooling are pumped from a 1,500 acre lake and are returned to the

lake after separation of unburned fuel and waste combustion products from the water. The water used for cooling the exhaust gases also has proven to be a most effective method for the reduction of noise emanating from the ram-jet.[3] Three sea-level cells (Exhibit 4) are employed to test ram-jet engines under simulated sea-level conditions in both free jet and connected pipe tests. The air supplied to the jet engines can be heated to the temperature of 650°F by a 35,000,000 btu per hour air heater. For sea-level tests, the engine exhausts directly to the atmosphere. Fuel for all test cells is furnished from a central storage and pumping system. Two hundred gallons of fuel per minute can be supplied the engines at pressures up to 500 pounds per square inch.

The second major division of the laboratory is a supersonic wind tunnel which is capable of speeds from subsonic to Mach 2.5[4] or roughly 1900 miles an hour through a rectangular test section 19 x 27½ inches in diameter (Exhibit 5). The Mach range is increased from subsonic in increments of approximately .25. These tunnel speeds are regulated by changing the nozzles.[5] Each nozzle is a single unit type construction. Optical glass windows 3 inches thick and 28 inches in diameter are installed in openings on each side of the test section. This provides for model view and for the use of various types of photography including Schlieren[6] and Shadowgraph.[7] These are photographic systems employed to provide visual observation and to record the flow characteristics in the test section and around the model being tested. The Schlieren system also provides visual observation of the air density, compression and behavior (Exhibit 6). The wind tunnel is of the closed circuit type and is normally operated as a closed circuit system. It can also be operated as an open circuit system for testing models of ram-jet engines at supersonic speeds. In the

VIEW OF SEA LEVEL TEST CELL OF THE ORDNANCE AEROPHYSICS LABORATORY

Center base of picture shows thrust stand on which ramjet engines are mounted for testing. Windows on extreme left, for observation, are shatter-proof and heat resistant. The heavy pipe construction shows a portion of a disassembled "Battleship" or heavy duty model constructed for repeated testing. The interior configuration is machined. The exterior is made for repeated assembly, disassembly and testing.

EXHIBIT 4

supersonic wind tunnel, pressure, humidity and temperature are controlled during tests. This control is effected for pressure by regulating the speed of the steam driven blowers circulating the air in connection with controlling the amount of air in the tunnel. The degree of humidity in the tunnel is controlled by bleeding dry air into the system. This air has been dried previously by an activated alumina system and is stored in a 10,000 cubic foot air storage sphere. When it is necessary to lower the dew point of the air in the tunnel, the system is so arranged that the wet air having too high a dew point may be purged from the system. The behavior of the model and the air in the model test section, in addition to being photographed by Schlieren or Shadowgraph, can also be recorded by the use of manometer banks and balance system. Manometer boards or banks

VIEW OF SUPERSONIC WIND TUNNEL OF THE
ORDNANCE AEROPHYSICS LABORATORY, DAINGERFIELD, TEXAS

Background shows multiple tube manometers used in measuring air pressures. The camera and mirrors in right center are a part of the Schlieren photographic system. The tunnel can operate at speeds up to approximately 1900 miles per hour through a rectangular test section 19 x 27.5 inches.

EXHIBIT 5

normally consisting of a multiple of tubes are employed for pressure measurements of the fluid. Force measurements—the aerodynamic forces exerted on the model—are measured by a balance system. There are three basic types of balance systems: (1) Internal balances—these are located inside the model itself, (2) whole or base balances for half wing models, (3) sting type balances for three dimension models. All three of these types employ resistance wire strain gages as the force sensing elements. These systems employ the principle of measuring unbalance essentially as employed in an electrical wheatstone-bridge type system. The motion of the model either compresses or elongates the fine wire element and results in a very small change of resistance in the wire which is picked up, amplified and recorded. By a process of prior calibration the amplitude of the resultant force is known. Electrical recording strain gage equipment is employed to measure all six components of force and moment, namely: lift, drag, side force, pitching moment, yawing moment, and rolling moment and is transcribed automatically by International Business Machines for rapid computation of results. The angle of attack and the angle of roll can be changed during runs without shutting down the tunnel.

Another interesting phase of the operation of the Ordnance Aerophysics

Laboratory is the power supply system. When the Ordnance Aerophysics Laboratory was first established in 1945, it was located on grounds in an idle blast furnace plant then owned by the Reconstruction Finance Corporation. The plant was under lease to the Lone Star Steel Company, which at that time conducted limited commercial operations. Negotiations had established that an idle blast furnace blower could be made available for the then desired research and development program and that additional blower capacity could be added at a relatively low cost. A four hundred and thirty-five thousand pound per hour steam generating plant with related equipment was also available along with electrical generators, railroad and other supporting facilities. This provided an ideal location for the establishment of a wind tunnel and a propulsion laboratory and for initial wind tunnel and propulsion studies for guided missile development. In 1947, the plant was purchased from the War Assets Administration by the Lone Star Steel Company exclusive of the land occupied and the equipment owned by the Department of the Navy. This industrial organization has expanded its commercial operations to include an integrated steel mill in addition to providing the Ordnance Aerophysics Laboratory wind tunnel and propulsion laboratory with the necessary power requirements and providing the Ordnance Aerophysics Laboratory joint use of rail, cafeteria and other necessary services. The power plant has been expanded commensurate with the research and development program, and today the necessary services for wind tunnel and propulsion laboratory operations are furnished under contract by the Lone Star Steel Company employing both Navy and Industrial owned equipment. The steam generating plant is fired by natural gas which is plentiful in the area at a relatively low cost. An electrical plant provides the necessary electrical energy for operations. Steam up to 270,000 pounds per hour is available at all times to drive the below listed steam turbine blowers and to furnish jet steam for high altitude operations:

A SCHLIEREN PHOTOGRAPH

Pictured is a Schlieren photograph taken in the Ordnance Aerophysics Laboratory supersonic wind tunnel showing shock wave characteristics about a hemispherical nosed-cylinder with blunt base at Mach No. 1.25. Strong detached shock wave ahead of nose, thin boundary layer along cylinder and expansion around shoulder followed by turbulent wake at cylinder base are interesting features.

EXHIBIT 6

	Rated Capacity SCFM 30 PSI	Rated Turbine H.P.	Rated Capacity When Operating in Series With IR, SCFM and 110 PSI Discharge
Ingersoll Rand	100,000	11,150	
DeLaval	97,800	11,110	
Elliott	33,000	10,650	100,000

The operation of this laboratory is on a share-the-cost-of-operation basis with operating costs of each facility of the laboratory prorated on a use basis to each military service. This operating cost is based on a semi-annual average hourly operating cost for each facility. Each military service contributes to a single contractual fund under which the laboratory is operated.

Laboratory testing of this type at supersonic speeds produces data vital to guided missile programs and greatly reduces the number of actual flight tests required. The importance and value, both from a time and monetary standpoint, of this type research and development is readily apparent. In a test laboratory the model may be tested for extended periods employing varying conditions without damaging the model and, at the same instant, providing large quantities of data at only a fraction of flight test data cost. Much more development data can be obtained in a laboratory test of this type than in a given flight test. A flight test missile is generally a "one-shot" type operation and can at best furnish only limited data, with the test vehicle quite often being destroyed, making laboratory type testing highly desirable. By the time the missile reaches the stage for flight testing, a large percentage of the needed operational data is already known and its design largely predicted and determined. In this type testing in both the propulsion and wind tunnel laboratories, the air is passed over and/or through the model to simulate flight and flight conditions as opposed to passing the model through the air as in a flight test.

In the operation of a research laboratory of this type, two principal problems present themselves: first, the operation of a facility which can record accurate test data by means of proper instrumentation and measuring equipment; and second, the ability to reduce and to know the meaning of the collected information and data. Inaccuracies in either of the foregoing can render the test information useless. This demands the design, fabrication and constant calibration and checking of many diverse and intricate measuring devices for both normal and special functions of OAL's testing and development work. Some of the facilities, instruments and test equipment are as much research and development as the missiles themselves and cannot be purchased as a standard item from the commercial market as they require specialized design, development and fabrication. This fact and the remote geographic location of OAL make it necessary that this operation have supporting facilities. There are, however, a number of instruments available from the commercial market which are used at OAL for the purpose intended or modified to meet the requirements of the guided missile research and development program. Included among these instruments are temperature recorders, tape recorders, sound recorders and analyzers, sensitive manifold pressure gages, thrust measuring systems, null (zero) balancing strain gage recorders, recording oscillographs, high speed cameras, cathode ray oscilloscopes and many others. The Ordnance Aerophysics Laboratory is also equipped to manufacture and fabricate, on a pilot basis, models used in ram-jet engine tests and supersonic wind tunnel tests. Many of these models require precise and intricate design and machining. For this purpose a well-equipped model shop and machine shop are operated. A design and facility group at the Ordnance Aerophysics Laboratory provides for new facility design and planning and for the modification of existing facilities as necessary to meet development requirements. A complete photographic and reproduction laboratory is also maintained. It is the function of this group to publish test data and technical reports, provide photographic reproduc-

tion, and handle the reproduction, of reports and data for the facility.

The work of the laboratory is largely of a classified nature carried out behind fenced security areas, and is under a constant 24 hour a day security guard. The laboratory does, however, carry out some unclassified tests and studies.

This unique facility has been equipped over 80 percent from surplus and excess sources without an exchange of funds, saving the taxpayers tens of thousands of dollars. Two important facts played a major role in the equipping and outfitting of this laboratory largely from surplus and excess sources. First, it was recognized that with the conclusion of World War II fewer dollars would be available for research and development in a period of declining military preparedness budgets. It was also recognized that with the rapid disestablishment of the nation's military machine and the accompanying rapidity of disposal of military equipment, material and supplies following World War II, large quantities of these items would be available and could be obtained and used to carry out research and development studies and fabrication of wind tunnel and propulsion models needed for the research programs. It was also recognized this could be accomplished largely without an expenditure of funds as the Government had previously effected payment and now held ownership to the needed equipment, materials and supplies. This approach made tremendous monetary savings and insured the availability of needed items during a period when many such items were not readily available on the commercial market. Milling machines, lathes, grinders, safes, benches, tables, desks, Butler buildings, nuts, bolts, nails and a thousand other items salvaged from the hurried abandonment of bases, equipment and materials following World War II made possible the equipping and outfitting of the Ordnance Aerophysics Laboratory.

The Naval Ordnance Aerophysics Laboratory today represents one of this nation's finest examples of utilization of a single facility by all branches of the Armed Services. The participation of all services at OAL dates prior to legislation unifying the military services. Since 1945, approximately 10,000 tests have been conducted in the wind tunnel and approximately 17,000 tests have been conducted in the propulsion laboratory to date. Wind tunnel models, propulsion models and missiles of finalized design are transported to the Ordnance Aerophysics Laboratory for testing and further development. At OAL the simulation of flight challenges the computations and predictions of theory. Models, missiles and varying configurations and designs of missile components of university, industrial and military groups from across the nation are tested. With the missile or the model to OAL come representatives of the sponsoring agencies. They select the test conditions for their missiles and models for the incubation process. The Ordnance Aerophysics Laboratory then provides the test conditions and conducts the tests — translating ideas, thoughts and theory into "birds" that can fly. It is in fact a guided missile incubator.

References

1. A group consisting of nine industrial organizations and fourteen universities each having a prime contract with the Navy's Bureau of Ordnance and each contractor receiving technical direction from a central university laboratory, the Applied Physics Laboratory of The Johns Hopkins University. The Applied Physics Laboratory of The Johns Hopkins University is assigned technical direction of the activities of these contractors by the Navy in addition to carrying out research and development studies in its own laboratories.

2. The ram-jet, commonly referred to as the flying stove pipe, is a high-speed rate of change projectile of tubular construction, propelled by the expulsion of heated gases.

3. Unmuffled ram-jet noise exceeds the pain region of the ear—120db. Water spray reduces noise level well below pain region of the human ear.

4. Mach 1 equals approximately 760 miles per hour (speed of sound at sea level). Mach number—the ratio of the velocity of a body to that of sound in the medium being considered.

5. A duct of changing cross section in which the fluid velocity is increased. Nozzles are usually converging-diverging, but may be uniformly diverging or converging.

6. From the German word meaning gradients or variations in gas density or striae Schlieren are made visible by an optical system, of the same name, which either cuts off or passes a larger change in light intensity owing to the slight refraction of the light passing through gas. Employed in wind tunnels to make visible turbulence and shock waves by showing the first derivatives of gas density directly.

7. A photographic system used in wind tunnel work employing a high intensity spark as the light source. Employed in wind tunnels to obtain photographs of air behavior including shock waves. This system shows the wave front but not density gradient.

POLYTETRAFLUOROETHYLENE —ITS PROPERTIES AND USES

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L. W. CORNELL, of Minnesota Mining and Manufacturing Company, presented this paper at the Spring Meeting of the American Society of Mechanical Engineers in Columbus, Ohio, in April 1953. The paper was published in the November 1953 issue of "Mechanical Engineering."

INTRODUCTION

Teflon * is the trade name for a comparatively new polymeric resin with unique properties, which is composed of tetrafluoroethylene, C_2F_4. The basic polymer is made and sold only by the du Pont Company, but a number of other companies process and sell Teflon in different forms for the ultimate consumer. Because of the fact that there is only one manufacturer of this material at present, it will be called by its trade name which is much simpler than its chemical name.

PROPERTIES AND USES

Electrical. Teflon is an excellent electrical insulator for many purposes, particularly where high-temperature conditions must be met. It may be used at temperatures as high as 500 F in continuous service and withstands intermittent exposure to 600 F. It also retains its flexibility and electrical properties as low as minus 100 F. A detailed list of electrical properties is given in Table 1. Its uniform dielectric constant and power factor over an extremely wide frequency range make Teflon very useful in many electrical applications. Its extremely broad temperature range enables it to be used in applications where other less expensive materials would not be suitable. There is increasing demand for Teflon-insulated wire and cable in jet aircraft, for example. Guided missiles are another application where Teflon is being used, again because of the temperature range encountered.

Aircraft motors and generators can be made smaller and more powerful with Teflon as slot liners, and so on. Coils and relays which must operate con-

* "Teflon" is a registered trade-mark of E. I. du Pont de Nemours & Company, Inc.

TABLE 1.—ELECTRICAL PROPERTIES OF TEFLON

Property	Conditions	Units	Value	Test method
Dielectric strength, short time	0.080 in.	volts/mil	400–500[a]	D149-44
Surface arc resistance	...	seconds	700[b]	D495-42
Volume resistivity	...	ohms-cm	10^{15}	D257-46
Surface resistivity	100% RH	megohms	3.6×10^{6}	D257-46
Dielectric constant	60 cycles	....	2.0	D150-47T
Dielectric constant	10^{8} cycles	....	2.0	D150-47T
Power factor	60 cycles	....	0.0005	D150-47T
Power factor	10^{8} cycles	....	0.0005	D150-47T

[a] Much higher in thinner film, see Table 2.
[b] Leaves no carbonized track.

tinuously at high temperatures use interlayer insulation of Teflon and Teflon-insulated magnet wire in the coils themselves.

High-temperature-resistant capacitors are now being manufactured with Teflon sheet insulation instead of paper or other material. The plastic is being molded into tube sockets for radio and radar components for aircraft. Insulating spacers for coaxial cable are being molded of Teflon.

In all these electrical applications and in many others, Teflon is being used in spite of its high cost because temperature requirements are being pushed further in both directions all the time. Teflon combines toughness, abrasion resistance, chemical resistance, excellent electrical properties, and high and low-temperature resistance in one material.

Chemical. Chemically, Teflon is about as inert as glass within its useful temperature range. It is attacked by molten alkali metals (sodium or potassium) and by fluorine and chlorine trifluoride, both at high temperatures and pressures. Other than these specific chemicals, published literature indicates that nothing has any effect on Teflon. This makes it ideal as a gasket material and liner in equipment in which high-temperature highly corrosive-chemicals must be handled. Since there is no known solvent for Teflon, it can be used in contact with any ordinary solvent without effect. Outside weathering also has no effect on Teflon. Samples exposed to natural aging for 5 years in Florida have shown no change.

In large stainless-steel or glass-lined equipment, many gaskets are needed, some of them quite large. The main body of the gaskets used on such equipment is generally made of asbestos, lead, rubber, cloth, or a combination of these materials, in order to provide the desired physical characteristics of compressibility, and so on. These materials must be protected from the action of the chemicals inside the equipment, and this is now commonly done by the use of a Teflon shield which is shaped to cover the top and bottom faces and the inside edge. Such gasket shields vary in size from a little over 1 in. ID to 5 ft ID.

Teflon is expected to find application as liners or bladders in connection with containers for white and red fuming nitric acid, when certain fabrication problems have been solved. Here, its ability to give chemical protection in thin flexible sheets is an important factor. Already it has proved its ability to withstand nitric and sulphuric-acid mixtures in actual use as gaskets on

equipment handling these acids at about 400 F. Teflon gaskets gave 18 months' service in comparison with 1 month for asbestos. This points up something of importance in connection with Teflon. In spite of its high price, it is frequently selected because no other known material can do the job. However, in many cases, such as the gasket just mentioned, Teflon actually may be cheaper in the long run because of the greatly increased service which it gives. In the gasket, valve, and diaphragm field, Teflon, in certain applications, is economically replacing such materials as asbestos, specialty rubbers, bronze, cast iron, and other materials.

Molded Teflon tubing with fairly thick walls is available for chemical work. Also, one company is producing large-sized pipe with relatively thin tough walls from a combination of glass cloth and Teflon. Small-diameter pure-Teflon tubing with very low wall thickness (as low as 0.005 in.) can be produced from a special form of Teflon film which has become available recently. This film will be described in detail under methods of fabricating Teflon and the forms in which it is available. The various types of Teflon tubing should broaden its use in the chemical-processing industry.

Physical and Mechanical. The high-temperature resistance of Teflon has been mentioned already. Its mechanical properties are very stable up to 500 F. For example, molded bars held at 480 F for 1 month show a loss of only 1 per cent in tensile strength. At 570 F the loss is 10 to 20 per cent. In addition to its high-temperature resistance it is serviceable to minus 100 F, and, in fact, instances of its use at temperatures as low as minus 320 F have been reported.

The plastic absorbs no water at all, and therefore its electrical, physical, mechanical, and chemical properties are unaffected by soaking in water, or by exposure to high-humidity atmosphere.

One of the most interesting properties of Teflon is its nonadhesiveness or slipperiness. This property has proved to be useful in many applications in the industrial field. For example, one large coating machine was giving a great deal of trouble with dirtying up of idler rolls in the oven on a certain coating job which was performed at intervals. The problem was solved by spiral-wrapping wide Teflon film around the roll, taping it down at each end of the roll. When the operation was finished the Teflon film was unwound and stored until it was needed again.

The baking industry has found that Teflon finishes can solve many of their problems. Cookie rolls, which carry a series of depressions into which dough is rolled to shape the cookie, have been coated with Teflon to prevent sticking of the dough and damage to the cookies. Rollers which shape bread dough into balls can be kept from sticking to the dough by applying a Teflon covering.

In packaging machinery, Teflon is very helpful. In heat sealers for sealing cellophane, foil, polyethylene, and the like, a liner of Teflon on the sealing shoes which contact the film being sealed will prevent its sticking to the shoe at the high sealing temperature. Also, in automatic packaging machines using glue or other adhesives, Teflon-coated rolls and fingers greatly reduce stoppages due to clogging of the machine with glue build-up and simplify the job of keeping the machine clean.

At least one instance has been reported in which it was found necessary to use a washer of $\frac{1}{32}$-in.-thick Teflon sheet between two moving metal parts in a small machine. The Teflon washer was the only means of eliminating squeaking and grinding between the metal faces. All other available plastics were tried, but only Teflon did the job.

Certain parts of pumps and valves used in highly corrosive service are be-

ing fabricated from Teflon. It can be molded, ground, and machined.

Teflon has rather poor heat conductivity and high thermal expansion. These points must be remembered in considering the use of the plastic as a packing around a pump shaft which will operate over a wide temperature range.

Work has been done in adapting Teflon in sheet form for diaphragms in pumps, controllers, and the like. Teflon can be of value, for example, where a flexible and corrosion-proof diaphragm is needed, which does not, however, have to withstand rapid and extreme flexing. A detailed list of physical and mechanical properties is given in Table 4.

FORMS OF TEFLON AVAILABLE

Molding Powder. This is one of the basic forms of Teflon sold by du Pont. It is a granular form which is used for making heavy sheet, molded shapes, and like products.

Molded Pieces. Sheets 1/16 in. thick or heavier as well as heavy-walled tubing, rods, bars, special shapes, and so on, are available from several companies which are set up to make and sell Teflon in such molded pieces. In this grouping there should be included molded gaskets, valve packings, valve seats, and the like. Also, at least one company can supply molded Teflon with copper or other metal firmly bonded to one face. Because of Teflon's high heat resistance, solder can be applied directly to the metal sheath.

Suspensoid. This is another basic form of Teflon resin. Particle size is much smaller than in molding powder. It is used for casting films, roll coating, spray coating, and the like.

Wire Enamels. These are suspensoids which have been specially processed for use in wire coating for the electrical industry.

Metal Primer. Du Pont produces three primers, one for copper, one for aluminum, and one for iron or other metals. They give improved anchorage of Teflon coatings to these metals.

Lubricated Paste. This is a specially prepared form which can be extruded for certain applications. It is made from coagulated dispersion.

Shaved Film. A log or bar is molded from a special molding powder. Film in various calipers as low as 2 mils is shaved from the circumference of this log. This shaved film is satisfactory for many applications where low pinhole count is not important. It is not oriented or tensilized to any extent.

Extruded Film. This is made by a special process from the lubricated paste mentioned previously. Extruded film is highly oriented and possesses greatly increased tensile strength in the machine direction. It also contains very few pinholes. It is currently available in calipers from 2 to 20 mils and has been made in higher calipers on special order.

Two forms of extruded film are available, i.e., the regular transparent variety, and the new self-fusing form mentioned in connection with thin-walled small-diameter Teflon tubing.

Transparent Extruded Film. This form of Teflon film is fully fused and is used in a wide variety of applications, including motor-slot liner, cable wrapping, capacitor dielectric, coil wrapping, gasket shielding for corrosive chemicals, and so on. It is a highly transparent, smooth-surfaced film with remarkably low pinhole count. Its dielectric strength runs as high as 2500-3000 volts per mil in 2 to 5-mil-caliper film. Typical electrical and physical properties for transparent extruded Teflon film are shown in Table 2.

TABLE 2.—PROPERTIES OF 5-MIL EXTRUDED TRANSPARENT TEFLON FILM

Property	Conditions	Units	Value	Test method
Dielectric strength, short time	....	volts/mil	2500	D149-44
Tensile strength:				
Longitudinal	77 F	psi	7000	D638-46T
Transverse	77 F	psi	2500	D638-46T

NOTE: Other values are essentially the same as in Tables 1 and 4.

Self-Fusing Extruded Film. This film is one of the newest forms of pure Teflon available and promises to extend the usefulness of the plastic a great deal. It is white and opaque and has much greater stretch and conformability than any of the regular transparent fused types. Its physical properties, as shown in Table 3, are quite different from those of the other types. It is seldom used in its unfused form, mainly because it is too soft and can be cut or abraded too easily. Its value lies in the fact that it does not slide too easily before fusion and that it bonds firmly to itself when fused in contact. Therefore it can be wrapped around articles which must be insulated electrically, or which must be protected from chemicals, and then fused in place to give a tough continuous Teflon covering. Because of its softness and pliability, it conforms well to various shapes around which it is wrapped. Of course, this sheet Teflon can be fused only onto metal or other material which can stand the high fusing temperature.

Cast Film. This film is cast in multiple steps from Teflon suspensoid. It is of very good quality and very expensive compared with other available Teflon films. Maximum caliper of cast film at present is 2 mils, but it is available as low as ¼ mil. Like shaved film, cast film is not oriented or tensilized.

TABLE 3.—PROPERTIES OF 5-MIL SELF-FUSING TEFLON FILM

Property	Conditions	Units	Value	Test method
Dielectric strength, short time	...	volts/mil	750	D149-44
Dielectric constant	60 cycles	....	1.7	D150-45T
Dielectric constant	10^8 cycles	....	1.7	D150-45T
Power factor	60 cycles	....	0.005	D150-45T
Power factor	10^8 cycles	....	0.005	D150-45T
Tensile strength:				
Longitudinal	77 F	psi	1300	D638-46T
Transverse	77 F	psi	160	D638-46T
Elongation:				
Longitudinal	77 F	per cent	175	D638-46T
Transverse	77 F	per cent	500	D638-46T
Density			1.4–1.5	

NOTE: After fusion, values for this film are similar to those for extruded transparent film.

Teflon Pressure-Sensitive Tape. Pressure-sensitive Teflon-filmbacked tapes have been made in combination with glass cloth. The adhesive used is one which vaporizes more or less completely at the maximum temperature to which the Teflon might be subjected in service, leaving little or no carbon residue. The pressure-sensitive adhesive simplifies the job of holding the Teflon in place during fabrication.

Surface Treatments. Recent work has produced Teflon sheet with very thin metal or other coatings or with surface characteristics different from those of regular Teflon so that better adhesion can be obtained to one side with conventional adhesives.

TABLE 4.—PHYSICAL AND MECHANICAL PROPERTIES OF TEFLON

Property	Conditions	Units	Value	Test method
Tensile strength	77 F	psi	1500–2500[a]	D638-46T
Elongation	77 F	per cent	100–200	D638-46T
Flexural strength	77 F	psi	Did not break	D790-45T
Stiffness	77 F	psi	60000	D790-45T
Impact strength:				
Izod	−70 F	ft-lb/in.	2.0	D256-47T
Izod	77 F	ft-lb/in.	4.0	D256-47T
Izod	170 F	ft-lb/in.	6.0	D256-47T
Hardness-durometer	....	....	D55-D70	D676-47T
Compressive stress	0.1% deformation	psi	1700	D695-44T
Coefficient of linear thermal expansion	77–140 F	per deg	5.5×10^{-5}	D696-44
Thermal conductivity	....	Btu/hr/-sq ft/-deg F/in.	1.7	[b]
Specific heat	....	Btu/lb/-deg F	0.25	....
Deformation under load	122 F–85 hr –1200 psi	per cent	4–8	D621-48T
Heat distortion temp	66 psi	deg F	270	D648B-45
Water absorption	....	per cent	0	D570-42
Specific gravity	....	....	2.1–2.3	D792-48T

[a] Higher for oriented film, see Table 2.
[b] Measured by Cenco-Fitch apparatus.

METHODS OF FABRICATION

In order to develop the inherent toughness and strength of Teflon, it must be fused or sintered above its transition temperature of 621 F. At this temperature Teflon changes from a fairly hard, semitransparent, waxy solid to a rather soft, amorphous, transparent gel. This change occurs at 621 F whether the Teflon has been sintered previously or not. Before this sintering is done the first time, Teflon is not suitable for most operations.

The manufacture of molded Teflon articles or shapes is best done by a

company which is set up to handle this type of work.

The various types of dispersions may be applied by spray gun or by dipping. They must then be dried and sintered at about 750 F. Successive coats are required to eliminate pinholes and give good chemical protection, and each coat should be fused separately. Further information on types of Teflon finishes available and their use may be obtained from the Finishes Division of du Pont.

Tapes can be used as a spiral wrap, which is done frequently for electrical insulation. For chemical protection, however, the self-adhering type which must be sintered after wrapping offers a better means of securing sealed protection.

The white, self-fusing Teflon sheet is easy to apply and to fuse around small shapes of regular surface, the simplest of which is ordinary copper wire. Here a simple spiral wrap with perhaps one-half overlap will give excellent results. Wrapped wire can be fused continuously by passing through a suitable oven maintained at 750 to 850 F, or even much higher if the wire is quite small. Wire speed depends on its size. It is well to quench the fused wire in water as soon as it comes from the oven.

The self-fusing Teflon may be applied over a wide variety of sizes and shapes, but special care is frequently required to insure fusion without crack formation. Wide sheets of Teflon have been made from the self-fusing type by overlapping at the edges over a suitable metal form and fusing while holding the film under tension.

Thin Teflon sheets can be well bonded to metal, even on a flat face, by using the proper Teflon primer for metal and fusing this film against it with pressure.

Technical help frequently may be needed from the supplier in working out applications for this self-fusing type of Teflon film.

Toxicology. A recent Technical Information Bulletin on Teflon from du Pont states the following:

"Minute amounts of gaseous fluorine compounds are given off at temperatures above 390 F and appreciable quantities are given off at 600 F or above. At approximately 750 F, polytetrafluoroethylene decomposes slowly. Adequate ventilation must be provided for any operation where these temperatures may be attained, because of possible toxicity of these gases."

DESIGNING A SUBMARINE NUCLEAR POWER PLANT

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MR. W. W. KUYPER of the Product Development Laboratory, Large Steam Turbine and Generator Engineering Section of the General Electric Company, is the author of this article. It was published in the September 1953 issue of the "General Electric Review."

There's more to designing a nuclear power plant for a submarine than putting a reactor and a steam turbine into a standard hull.

Conventional power plants for submarines pose enough problems: a nuclear power plant is many times more complex.

The power plant—regardless of the type—must be so located that the ship will be dynamically stable in an upright even-keel position, both submerged and on the surface, and it must be capable of control by adjustment of buoyancy tanks.

This is the conventional problem of undersea craft—a problem that forces limited patterns of arrangement on both the shipbuilder and the equipment supplier. For instance, weights and centers of gravity must be watched far more closely than in surface vessels that can usually sink a little deeper in the water. It's too easy to make a nose-heavy or tail-heavy submarine, or one that's heavier than its displaced volume of water, even when the design says it isn't.

CONVENTIONAL SYSTEMS

On the nuclear submarine now being built, the engine room itself is filled with machinery that is well known and understood. The turbines and motor-generator sets are so mounted that ship structure dislocations, within certain limits, won't disturb the alignment of the assemblies. The condensers can withstand submergence pressures, and the piping is designed to operate under thermal and mechanical stresses in close quarters. The air-conditioning system condenses all the steam that escapes, and the electric system supplies power where it's needed. Proper means are provided for safety release of boiler pressure at full submergence.

All equipment is designed to meet Navy shock requirements. And because the life of the vessel may depend on it, the response speed of the entire propulsion system is more rapid than for surface vessels, and considerably more rapid than for central station power plants. The control of all the vital auxiliaries is centralized to assure quick

handling in emergencies. All equipment is designed to tolerate unusually large degrees of pitch and roll because submarines are relatively unstable.

The foregoing are all problems in applying well-known types of equipment and systems to a highly refined end product. But when you take a radically new type of power plant and attempt to apply it, not only does practically all of the preceding apply, but many new problems also enter the picture.

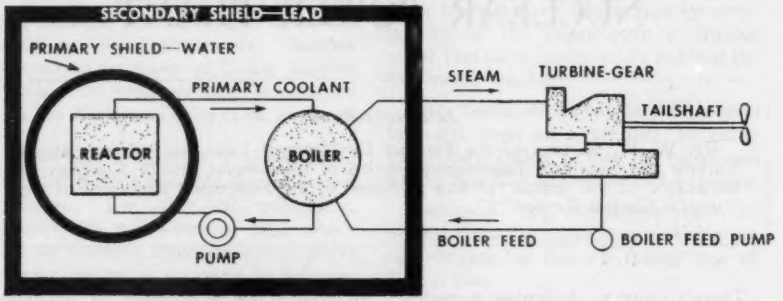

FIG. 1—SUBMARINE NUCLEAR REACTORS.

The two submarine nuclear power plants now being built have been designated: STR—Submarine Thermal Reactor, water coolant; and SIR—Submarine Intermediate Reactor, sodium coolant. The thermal reactor effects most of the fissions with neutrons at slow or thermal speeds; the intermediate at intermediate speeds.

In both types of reactors, the primary coolant—water or sodium—is pumped through the reactor and boiler in series to transfer the heat to the steam. The steam drives the main turbine and the auxiliaries necessary to run the plant.

The region outside the reactor is protected from the neutrons in the reactor. Neutrons tend to make radioactive anything they strike. Accordingly, the reactor itself is surrounded by a primary shield to stop the neutrons. Light elements, such as the hydrogen in water, are effective for this purpose when combined with nuclear poisons.

The coolant becomes gamma radioactive when it passes through the reactor. To protect personnel from the dangerous gamma rays, a shield, preferably of high density, surrounds all components that contain the primary coolant.

The problems associated with both power plants are similar, and for general unclassified discussion they can be treated together.

For both STR and SIR, the power plant designers have relied directly on the Electric Boat Division of the General Dynamics Corporation for the solution of the ship problem.

UNCONVENTIONAL SYSTEMS

In designing a nuclear power plant for a submarine (Fig. 1) four factors dominate all design considerations within the secondary shield:

1 Because the secondary shield is thick and heavy, it must be kept as small as possible, and the components within it must be compact and closely packed.

2 The equipment within must be located for easy servicing.

3 For all practical purposes, a reactor, once in operation, never stops producing heat. (Actually, its rated output falls off rapidly at first, then slowly over a long period of time.) Therefore, adequate cooling must be provided at all times, even in the event of a power failure.

4 The systems can be designed as hermetically sealed units that won't require any additional coolant to be added during a voyage. Or they can be designed for very low leakage—small amounts of coolant would then be added during the voyage.

There are two choices of reactor compartment design . . .

1 Allow entry to the compartment for replacement or repair.

2 Design it so that all the vital components can be removed without entry to the compartment.

The second idea is possible only with simple systems; and it has a further drawback in that some of the basic piping may be inaccessible.

Special equipment for dockside or tender servicing must be carefully planned and developed. If any special coolants are required, they must be supplied, and provision must be made for handling large quantities of radioactive material. In this regard the designer must always remember the necessity of adequate safeguards for the surrounding community.

Emergency cooling—cooling the reactor after a power failure—by natural convection of the primary coolant requires that adequate pressure heads be available under extreme conditions of pitch and roll, that the primary coolant remain in the system, and that it be allowed to transfer its heat somewhere. An auxiliary system is probably required for final heat transfer to the sea.

UNCONVENTIONAL COMPONENTS

Systems are made up of components: they, too, present new problems to the designer.

Because the primary coolant becomes radioactive, and also to avoid pumping excessive leakages back into the system, it's important that the valves don't permit leakage from the system. If water is used as a coolant, it involves high-pressure valves with sealed-in electric actuators, or piston-operated valves with the necessary auxiliary systems. It's easy enough to write the specifications, but it's difficult to design and develop reliable valves and equipment for this type of service.

If liquid metal is the coolant, the valves must be sealed against lower pressures. Even so, the hazards associated with a small leak of sodium are probably greater than with water. In addition to the various paths of development open for water valves, a bellows-sealed stem appears practicable at the lower pressures. Again, the problem is to assure reliability.

To avoid leakage where water is used as a coolant, pumps have been developed in which the motor is submerged in the primary fluid.

When you consider the application of liquid metal pumps in submarines, it is immediately apparent that there must be no leakage. Because of this, you must use either electromagnetic pumping, or canned and submerged motors driving centrifugal pumps. Both types are practicable; both require extensive and concentrated development and design effort to bring them to an adequate stage of reliable performance. Another difficulty is that electric insulation in the pumps must be able to withstand the radiation of the fluid being pumped.

Regardless of what system is used, each must have additional and special equipment: purifiers for the fluid, heaters for pipes where sodium is used (melting point 208°F), and leak detection, pressure, temperature, and flow indicators.

The boilers for nuclear power plants using water as a coolant have an inherently low temperature drop for heat transfer. The average temperature of

the water must be sufficiently below the boiling point at the pressure used to avoid local boiling in the reactor. This in turn leaves little temperature margin for the boiler when even moderate pressures are used in the steam system. The end result is boilers of large surface area that must be shielded by the secondary shield to protect the crew from the induced radioactivity in the coolant.

With sodium as a coolant, much larger temperature drops are available (boiling point of sodium at one atmosphere is 1621°F). But using such high drops and temperatures brings up the serious problems of thermal dislocations and shock. In addition, because of the violent chemical reaction between sodium and water, it's necessary to provide a double barrier between the two fluids. This further hampers the designer because it requires construction of devices that are unusual and that tend to be awkward to manufacture and maintain. Close design requires knowledge that can be made available only by extensive fundamental study and experimentation.

REACTOR PROBLEMS

Reactors for the submarine power plant—or for any nuclear power plant—are combinations of 1) nuclear fuel, 2) a moderator to slow the neutrons so that they are more effective and so that less fuel is required, 3) a coolant, 4) structural material, and 5) controls. All these items fight for space within the primary shield. To be nuclearly efficient, the reactor must be small. The result is a tight design in which enough heat for a relatively large power output is taken from a very small volume. That the heat-transfer rates must be high is obvious. As is usual in engineering structures, the heat is not generate uniformly, and the problem is thereby complicated.

Another problem peculiar to liquid-metal reactors is that of thermal shock. Liquid metals have high thermal conductivities that give large temperature dislocations in the structure with sharp load changes such as "scram" (emergency shutdown), or even with rapid load changes.

Control can be effected most readily by the insertion of nuclear poisons. Unfortunately, these poisons must be inserted with reasonable uniformity of distribution throughout the core. Operation must be handled either through mechanical seals, or by mechanisms contained in the primary fluid. The accuracy of positioning and speed of motion required is similar to that on steam turbines.

Another important factor is that the success of a reactor is directly dependent on the reloading means. Even if the initial loading is made for the lifetime of the equipment, unloading is needed in the early stages of the development program to determine just how the fuel elements are getting along. The problem is further complicated by the fact that the heat from the fuel elements can't be shut off completely after they have operated for some time. Therefore, the designer must decide whether he will reload in one piece, or piecemeal. With a water system, he must provide proper closures of a heavy pressure vessel; with sodium, he faces the added complication that he must maintain an inert-gas atmosphere over the work.

The design of a nuclear power plant for a submarine involves problems that are extensions of old and time-proved techniques. The designers recognize that unforeseen problems will arise, but they're fully confident that these new power plants will be successful, and that they will provide a new level of performance for submarines.

MAGNETIC PERMEABILITY OF SO-CALLED "NON-MAGNETIC" METALLIC MATERIALS

M. R. GROSS

THE AUTHOR

received a B.S. Degree in Metallurgical Engineering from the University of Pittsburgh in 1939. After graduation, was a Metallurgical Observer at the Homestead Plant of the Carnegie-Illinois Steel Co. for approximately one year. From 1940 to 1944, was Assistant to the Melting Superintendent at the Universal-Cyclops Steel Corporation, Bridgeville, Pennsylvania. In 1944, joined the U. S. Naval Metals Laboratory, Munhall, Pennsylvania, as Metallurgist. He was later promoted to Associate Metallurgist and in 1946 was transferred to the U. S. Naval Engineering Experiment Station, Annapolis, Maryland, where he is currently employed. At the Station he has held various positions in the Metallurgical Laboratory, and his present capacity is Head of the Mechanical Metallurgy Branch.

To the uninitiated, the measurement of magnetic properties of non-magnetic materials must appear not only a useless research program, but completely contrary to the fundamental laws and principles of magnetism. Such would certainly be the case if all so-called "non-magnetic" materials were truly non-magnetic. As it is, however, the term "non-magnetic" has been loosely applied to any material which does not offer appreciable attraction to a magnet. As a consequence many "non-magnetic" materials do exhibit feeble, but measurable, magnetic properties such as permeability, coercive force, and residual induction.

Developments in mine warfare have dictated the necessity for minesweepers of very low magnetic signature, capable of combating the improved magnetic mine. During the design and construction of these new type vessels, it became necessary to determine the magnetic behavior of a wide variety of "non-magnetic" metallic structural materials. Much of the data either is new or has never been combined and presented in the literature. It is the purpose of this article to present the results and conclusions obtained from a large number of permeability tests and to discuss the behavior of various classes of materials.

PERMEABILITY

Before proceeding with the detailed account of the equipment and data, the magnetic properties determined herein will be briefly discussed. Terms related to magnetic testing are precisely defined by ASTM[1], and no attempt will be made to restate these terms. Instead, an effort will be made to explain them in the simplest possible manner.

Metallic materials can be divided into three classes insofar as their magnetic properties are concerned. These are (1) ferromagnetic, (2) paramagnetic, and (3) diamagnetic. The differences in the classes lies in their behavior in a magnetic field. Elongated samples of a ferromagnetic material assume a position parallel to the magnetic field and become strongly magnetized. On the other hand materials of classes (2) and (3) become weakly magnetized and assume positions either parallel to the field (paramagnetic) or perpendicular to the field (diamagnetic); in the latter case a non-uniform field is a necessary condition. The effects are relatively feeble in the last two classes of materials and for all practical purposes the paramagnetic and diamagnetic substances are called non-magnetic. It is important to note at this point that only three of the common elements are ferromagnetic. These are iron, nickel, and cobalt.

Magnetic permeability may be defined in one sense as the ability of a material to concentrate lines of magnetic force, or flux. In more specific terms the normal permeability, μ, is defined as the ratio of normal induction to the magnetizing force. The magnetizing force is designated by the symbol H; the unit is the oersted. Normal induction is designated by the symbol B; the unit is gauss. Ordinarily, the permeability of a substance is expressed in terms relative to air or vacuum; air being artibrarily given a normal permeability of 1. Both ferromagnetic and paramagnetic substances have permeabilities greater than 1, whereas diamagnetic substances have permeabilities less than 1. Furthermore the permeability is constant in all field intensities for truly paramagnetic and diamagnetic materials whereas the permeabilities of ferromagnetic substances vary.

Magnetization is an irreversible process. When the magnetizing field is reduced from an initial high value, the induction in the material does not decrease along the same curve as it did when it was first magnetized. When magnetization is reduced to zero, a certain residual induction, Br, often called remanence, remains. This residual induction can be removed by applying a field in the opposite direction. The value of the field required to reduce the normal induction, B, to zero is called the coercive force and is denoted by Hc.

Throughout this article data on the "ideal permeability," μ ideal, of various materials will be presented. The "ideal permeability" differs from the normal permeability both in magnetic environment and technique. The conditions surrounding the "ideal" tests were proposed to simulate the effects on permeability caused by mechanical shaking or vibration while exposed to the earth's magnetic field. The method used in determining the ideal permeability will be dealt with later.

METHOD OF TEST

The measurements described herein were obtained jointly by the U. S. Naval Engineering Experiment Station, Annapolis, Maryland, and the U. S. Naval Ordnance Laboratory, White Oak, Maryland. The Engineering Experiment Station performed the strong field (100-200 oersteds) normal permeability measurements whereas the Ordnance Laboratory conducted the weak

field (0.5-20 oersteds) normal and ideal permeability tests.

If the normal induction in a feebly magnetic material were determined directly, as a step in the determination of the permeability of such a material, the sensitivity of such a measurement would be too low to be practicable. As mentioned previously, permeability is equal to B/H. B is made up to two factors: the magnetizing force acting, H, and the intrinsic induction designated as B_i. In low permeability testing, H is ordinarily a large quantity, while B_i is quite small. For the sake of both precision and accuracy, the desirable procedure becomes the measurement of H and B_i separately. Then the sought for normal permeability is determined by the relations:

$$\text{Normal permeability } (\mu) = \frac{B}{H} = \frac{H + B_i}{H} = 1 + \frac{B_i}{H}$$

The ratio B_i to H is called the intrinsic permeability, μ_i, and reflects the permeability of the material in excess of that in air.

A Fahy Low-mu pereameter was used in performing the tests at the Engineering Experiment Station. This is one of several standard instruments used to measure the permeability of feebly magnetic materials. Detailed descriptions of the apparatus are available in the literature and a schematic wiring diagram and test procedure are given under Method No. 2 of A.S.T.M. Method of Test A342-49. Briefly, the apparatus consists of (1) a control box containing variable resistances, an ammeter, a reversing switch, and a calibrated inductance; (2) a solenoid for producing a relatively uniform magnetic field; (3) a specimen holder which fits inside the solenoid and contains two coils, one (coil H) having a plastic core and the other (coil B) surrounding the specimen, and (4) a ballistic galvanometer. Prior to inserting the specimen, the galvanometer is calibrated with the known inductance and coils B and H are balanced so that when the field in the solenoid is reversed, the differential EMF between coils B and H is zero. The specimen is inserted in the holder, demagnetized, and then cyclically magnetized. The magnetizing force, H, is measured by reversing the field of the solenoid and noting the galvanometer deflection caused by the EMF produced in coil H by induction. The intrinsic induction, B_i, is then measured by noting the galvanometer deflection caused by the differential EMF produced between coils B and H as a result of the specimen. Knowing the circuit constants, intrinsic permeability and the normal permeability are calculated from the relationship shown above. Fig. 1 is a general view of the permeameter at the Engineering Experiment Station.

Because of the weak magnetizing fields used in the Ordnance Laboratory's tests, their apparatus was specially constructed for high sensitivity. Fig. 2 schematically shows the circuit used in the tests. Essentially it consists of (1) a reliable, stable, high sensitivity fluxmeter and control box; (2) a double wound solenoid for producing relatively uniform d-c and a-c magnetic fields; (3) a search coil centered inside the solenoid; (4) a variable mutual inductor; (5) d-c power supply, ammeter, resistors, and reversing switch; and (6) an "idealizer." The "idealizer" is essentially a variable transformer designed to bring the idealizing current supplied to the a-c winding of the solenoid smoothly down to zero.

The weak field normal permeabilities were measured by either of two methods. In both methods, the "idealizer" is removed from the set-up. In the first method the current in the d-c

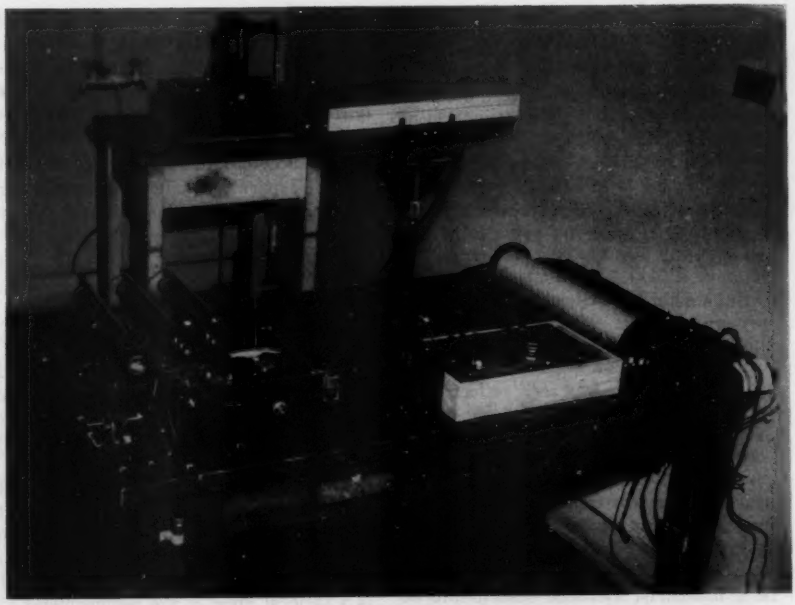

FIG. 1—Low Mu-Permeameter at E.E.S.

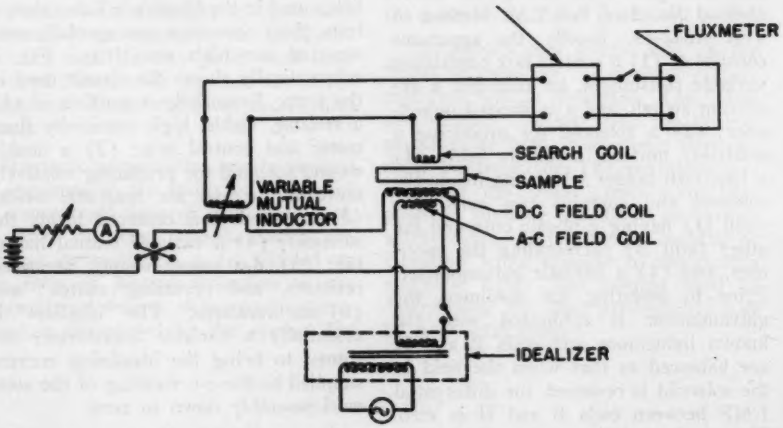

FIG. 2 SCHEMATIC DIAGRAM OF THE N.O.L. CIRCUIT FOR MEASURING PROPERTIES OF "NON-MAGNETIC" MATERIAL

winding of the solenoid is adjusted to give the desired field. Without a specimen in the search coil, the variable mutual inductor is adjusted to give zero deflection of the fluxmeter when the d-c field is reversed. The specimen is then centered in the search coil and the fluxmeter deflection noted for a current reversal. Knowing the circuit constants the normal permeability can then be calculated.

In the second method, the mutual inductor is removed from the circuit. The specimen is centered in the search coil and the desired field applied. The sample is then pushed out of the search coil and solenoid. There is a sudden change in flux in the search coil due to this action, which causes a deflection of the fluxmeter. The normal permeability is then calculated from this deflection.

The "ideal permeability" is determined with the same set-up as used for the second described method except that the "idealizer" is now introduced. The samples are "idealized" by applying a 0.5 oersted d-c magnetic field and then superimposing an a-c magnetic field of 50 oersteds or greater. The a-c field is then diminished to zero. The sample is pushed out of its search coil without changing the d-c field and the fluxmeter is read. The fluxmeter reading thus obtained is proportional to the magnetization of the sample, B-H. The ideal permeability is then computed.

$$\mu \text{ ideal} = 1 + \frac{B - H}{H}$$

It was recognized early in the test program that unusual magnetic requirements would pose a problem in the procurement and inspection of low-permeability materials, structures, and components. Faced with this problem, a simple field inspection device was developed at the Engineering Experiment Station. This device, for which a patent application has been filed, is called a permeability indicator and is shown in Fig. 3.

FIG. 3—Permeability Indicator.

The permeability indicator indicates the normal magnetic permeability of low permeability materials. The indicator is of limited accuracy and is not intended to replace the laboratory permeameter for accurate and precise measurements. The advantage of the indicator lies in its simplicity of operation combined with extreme portability. This enables inspectors and others to intelligently examine and judge materials and structures in the field and thus determine whether or not more elaborate laboratory tests are required.

The operation of the indicator is based on the mutual attraction of a permanent bar magnet for a known standard and an unknown material. The indicator in general use by the Navy incorporates four known or equivalent permeability inserts, namely 1.2, 1.6, 2.0 and 2.5. In use, an insert is placed in the seat of the indicator; the magnet being attracted to the insert by a force dependent upon the insert's permeability. While holding the indicator in the hand, the projecting end of the magnet is placed in contact with the material being tested. The indicator is then moved away in a direction normal to the surface. If the test material has a permeability *higher* than that of the insert, the magnet *will break contact with the insert* as the indicator is moved away. On the other hand, if the permeability of the test material is *lower*, then the magnet will *break contact with the test material* as it is moved away. Thus, by interchanging inserts, it is possible to bracket the permeability.

TABLE I

PROPERTIES OF BRASSES AND BRONZES

Type or Name	Specification	Condition and Treatment	Chemical Composition in %										Mechanical Properties				Hardness	Normal Permeability—μ					Ideal μ H=0.5 at +24°C	iHc	Br	Remarks
			Cu	Zn	Sn	Pb	Fe	Ni	Al	Mn	Si	Other	T. S. in psi	Y. S. (.5%) Ext.	Elong. %—2"	R. A. %		H=0.5			H=20	H=100	H=200				
																		−40°C	+24°C	+49°C	+24°C	+24°C	+24°C				
Yellow Brass	ASTM-B36 No. 8	Half Hard	65.3	34.5	None	.06	.08						54,100	33,600[1]	42	66						1.00	1.00				
Cartridge Brass	MIL-B-895 (Ships)	Full Hard	70.7	29.2	None	.02	.02						76,200	58,000[1]	18.5	57						1.00	1.00				
Brass	SAE-72	Wrought																1.04	1.04	1.06	1.05[4]			1.75	25.15	2.58	
Naval Brass	SAE-73	Wrought																<1.004	<1.004	<1.004	<1.004			<1.004	—	<0.02	
Red Brass	SAE-40	As-Cast																<1.02	<1.02	<1.02	<1.02			<1.02	21.08	0.07	
Bronze	AMPCO 72	Sand Cast	88.14	Bal	8.67	.40	.02	.33					46,000	24,000	26.0	26.0	70 BHN					1.00	1.00				
Bronze	AMPCO 79	Sand Cast	86.84	Bal	10.39	.12	.03	.12					46,000	22,000	24.0	24.0	75 BHN					1.00	1.00				
Bronze	AMPCO 675	Cent. Cast	59.66	Bal	1.02		1.14			.25			70,000	32,000	41.0	47.0	120 BHN					1.09	1.09				
Al-Bronze	N.D. 46B18 Cl .1 (AMPCO 12)	Sand Cast	87.09				3.16	.21	9.50	.02			80,000	30,000	40.0	40.0	132 BHN	1.23	1.19	1.20	1.20	1.17	1.18	1.54	29.72	7.69	
Al-Bronze	AMPCO A-3	Sand Cast	88.6				.98	.07	10.3	.01			84,000	31,500	24	26	143 BHN					1.05	1.05				
Al-Bronze	AMPCO A-3	Forged	89.0				1.4	.12	9.4	.03			85,000	39,000	26	26	143 BHN					1.05	1.05				Broken—μ=1.06 @ 100 H Static Torsion—μ=1.06 @ 200 H
Al-Bronze	AMPCO 8	Extruded	90.63				2.31	.11	6.92	.01			73,000	33,000	42.0	47.0	157 BHN					1.16	1.17				
Al-Bronze	AMPCO 8	Rolled	90.6				2.2	.16	7.0	.02			75,000	38,500	49	50	143 BHN					1.10	1.16				Broken—μ=1.13 @ 100 H Static Torsion—μ=1.14 @ 200 H
Al-Bronze	AMPCO 16	Sand Cast	85.83				3.36	.43	10.31	.05			90,000	32,000	22	22	146 BHN					1.28	1.29				

Al-Bronze	46 B18 Cl3 (AMPCO 18)	Wrought															1.16	1.15	1.20	1.19[4]			1.25	17.36	5.68	
Al-Bronze	AMPCO 18	Sand Cast	85.6				3.6	.22	10.5	.03		94,000	36,500	19	18	156 BHN					1.26	1.27				
Al-Bronze	AMPCO 18	Extruded	85.31				3.53	.28	10.82	.03		95,000	45,000	12	8	175 BHN					1.35	1.36				
Al-Bronze	AMPCO 18	Forged	85.8				3.5	.22	10.3	.03	.13	93,300	40,000	21	21	149 BHN					1.18	1.18				Broken— μ=1.19 @ 100 H Static Torsion— μ=1.14 @ 200 H
Al-Bronze	AMPCO 20	Extruded	84.18			.10	3.80	.47	11.37	.03	.03	95,000	40,000	5.0	4.5	223 BHN					1.22	1.25				
Al-Bronze	AMPCO 22	Extruded	81.35				4.53	.39	13.68	.03		85,000	70,000	0.5	0.0	331 BHN					1.17	1.19				
Al-Mn Bronze	N.D. 46B29a-Cla (AMPCO 66)	Sand Cast	62.76	Bal			3.74		5.52	3.78		115,000	65,000	15.0	15.0	212 BHN					1.09	1.09				
Al-Mn Bronze	N.D. 46B29a-Clb (AMPCO 64)	Sand Cast	65.00	Bal			2.37		4.14	3.69		92,000	48,000	22.0	22.0	183 BHN	1.22	1.22	1.20	1.23	1.27	1.24	1.33	12.10	3.68	
Al-Mn Bronze	AMPCO 435	Cent. Cast	86.60				.02		9.99	3.05	.26	103,500	30,000	21.0	23.0	156 BHN					1.00	1.00				
Al-Mn Bronze	AMPCO 435 H. T.	Sand Cast Quenched & Drawn	87.52				.08		10.12	1.88	.38	94,500	46,500	13.0	15.2	174 BHN					1.00	1.00				
Al-Ni Bronze	N.D. 46B17 (AMPCO 45)	Extruded	81.57				2.63	5.47	9.58		.73	110,000	50,000	9.0	9.0	220 BHN	<1.02	1.04	<1.02	<1.02	1.02	1.02	1.04	83.16	1.80	
Al-Ni Bronze	AMPCO 46-22	Sand Cast	80.6				4.5	4.2	10.6	.05		112,000	66,500	17	23	207 BHN					1.05	1.07				
Al-Ni Bronze	AMPCO 46-22	Cent. Cast Quenched & Drawn	80.46				4.73	4.52	10.24	.03		120,000	70,000	18.0	18.0	223 BHN					1.21	1.21				
Al-Ni Bronze		Cast															1.24	1.22	1.19	1.23[4]	1.06	1.06	1.23	1.26	3.00	
Hydraulic Bronze	N.D. 46B23e (AMPCO 74)	Sand Cast	85.47	Bal	4.16	4.69	.03	.50				38,000	20,000	26.0	26.0	60 BHN					1.00	1.00				
Mn-Bronze	46B15e	Wrought	58.63	39.49	.91	.22	.72		None	.02		74,400	35,100[5]	33.7	45.8	137 BHN	1.08	1.09	1.11	1.10	1.09	1.09	1.11	39.21	5.14	
Mn-Bronze	N.D. 46B3f (AMPCO 62)	Cent. Cast	59.40	Bal			1.13		1.16	.33		75,000	29,000	35.0	35.0	143 BHN	1.10	1.14	1.09	1.10	1.10	1.09	1.15	25.21	3.13	
Mn-Bronze	N.D. 46B3f	Prop Casting	57.93	39.18	.78	Nil	.69		.65	.78		46,000-60,000		8.0-22.		103-108 BHN	1.09	1.09	1.09	1.11[4]	1.09	1.10	1.25	10.55	2.07	

TABLE I (Cont.)

Type or Name	Specification	Condition and Treatment	Chemical Composition in %										Mechanical Properties				Hardness	Normal Permeability— μ						Ideal μ H=0.5 at +24°C	iHc	Br	Remarks
			Cu	Zn	Sn	Pb	Fe	Ni	Al	Mn	Si	Other	T. S. in psi	Y. S. (.5%) Ext.	Elong %—2"	R. A. %		H=0.5			H=20	H=100	H=200				
																		−4.°C	+24°C	+49°C	+24°C	+24°C	+24°C				
Mn-Bronze		As Cast Beta Phase	53.2	42.79		Nil	1.75		1.22	1.14			85,500	15,700[3]	31.5	27.8						1.18	1.19				
Mn-Bronze	SAE-43	As-Cast																1.10	1.10	1.12	1.12[4]			1.17	18.35	4.76	
Phosphor Bronze-5%	ASTM B139-A	Half Hard	94.5	Nil	5.4		.07						63,500	44,500[1]	38.5	73.8						1.00	1.00				
Phosphor Bronze-8%	ASTM B139-C	Full Hard	91.5	Nil	8.4		.06					P .13	94,800	64,000[1]	22	60						1.00	1.00				
Phosphor Bronze-10%	ASTM B139-D	Full Hard	89.4		10.5		.07					P .14	90,500	55,000[1]	34	66						1.00	1.00				
Leaded Tin Bronze (Comp. "M")	N.D. 46B8i	Sleeve Casting	89.	3.5	5.7	1.4		.5				P .011	40,500	18,500[2]	29.5	29.7		<1.02	<1.02	<1.02	<1.02	1.00	1.00	<1.02		<0.02	Broken— μ=1.00 @ 100 Static Torsion— μ=1.00 @ 200
Leaded Tin Bronze (Comp. "M")	N.D. 46B8i (AMPCO 71)	Sand Cast	88.77	Bal	6.19	1.76	.04	.11					40,000	20,000	30.0	30.0	65 BHN	<1.02	<1.02	<1.02	<1.02	1.00	1.00	<1.02		<0.02	
Bronze	SAE-620	As-Cast																<1.004	<1.004	<1.004	<1.004[4]			<1.004		<.002	
Bronze	SAE-622	As-Cast																<1.02	<1.02	1.02	<1.02			<1.02		<0.02	
Tin-Nickel Bronze	N.D. 46B32 Type I	Cast	84.9	3.1	6.0			5.9					50,500		43							1.00	1.00				
Tin-Nickle Bronze	N.D. 46B32 Type II	Cast	86.9	2.5	4.8	1.7		4.0					39,000		20							1.00	1.00				
Tin-Nickel Bronze	AMPCO 50	Sand Cast	83.81		10.26	2.48	.03	3.45					47,000	27,000	20.0	20.0	86 BHN					1.00	1.00				

NOTES: [1] Johnson's Limit [2] 0.2% Set [3] Proof Stress [4] H ≧ 7.0

RESULTS OF TESTS OF NON-FERROUS MATERIALS

BRASSES AND BRONZES

The brasses and bronzes tested are tabulated in Table I. For convenience, the appropriate specifications, chemical composition, mechanical properties, and hardness have been listed in addition to the magnetic permeability when available. The data definitely indicate that *the only element which affects the permeability of these alloys is iron.* In every instance where the percentage of iron is low the normal permeability is 1.00. There appears to be no definite relationship between the iron content and the permeability principally because permeability in these alloys is structure sensitive, i.e., it varies with casting conditions, heat treatment, rate of solidification, amount of hot work, etc. There is no evidence that the condition in which the materials are furnished, this is, cast or wrought has any direct bearing on the trend of the permeability.

In the "Remarks" column of Table I, magnetic test results are given for several static torsion specimens. These specimens were twisted in a static torsion machine until broken and the magnetic characteristics of the twisted section then measured. It is apparent that the magnetic properties of none of the materials tested in this manner were affected by cold work.

Table II is a tabulation of results obtained on several Ampco aluminum bronzes subjected to various heat treatments. Examination of this data reveals that quenching from 1200°F is not effective in reducing the as-cast permeability of the Ampco 18 alloy. Quenching from 1650°F gave inconsistent results in that it reduced the permeability of the Ampco 18 but increased that of the Ampco 45. In general, the double treatment (Treatment D) substantially lowered the permeability of all of the alloys tested except Ampco 45. This alloy was initially low, however, in the as-cast condition.

A statistical analysis of the composition and permeability data of Table II resulted in the following:

(a) The concentration of iron is an important factor in determining the permeability of these alloys.

(b) The concentration of nickel has no effect on the permeability of these alloys.

(c) Manganese content *does* affect permeability. The nature of its effect, however, is not clear-cut. Alloys having .03% Mn or more give a different relationship with Fe than those having less than this amount, the higher Mn alloys tending toward lower permeabilities.

CUPRO-NICKEL ALLOYS

The magnetic characteristics of the cupro-nickel alloys tested are shown in Tables III and IV. In Table III only the 80:20 Cu — Ni + Fe alloy showed a permeability substantially greater than 1. This particular alloy behaved ferromagnetically as indicated by the changes in permeability with field strength. It is to be noted that all of the alloys had low permeability in the annealed condition.

Table IV presents the magnetic properties of a group of 90:10 Cu — Ni alloys. Seven lots containing various amounts of iron were subjected to three different heat treatments. Heat Treatment "A," an annealing treatment, showed no changes in permeability or coercive force with varying iron contents. Heat Treatment "B," designed to produce a fairly complete precipitation of the iron content, shows increases in

TABLE II

EFFECT OF HEAT TREATMENT ON THE ROOM TEMPERATURE MAGNETIC PROPERTIES OF SEVERAL ALUMINUM BRONZE SAMPLES

Specification	Chemical Composition—%					Total No. of Samples	Avg. Normal Permeability (μ) and Avg. Coercive Force H_c											
							Treatment A			Treatment B			Treatment C			Treatment D		
	Cu	Al	Fe	Ni	Mn		100H	200H	H_c	100H	200H	H_c	100H	200H	H_c	100H	200H	H_c
Ampco 18—S. C.	86.10	10.63	3.11	.13	.01	8	1.25	1.26	2	1.24	1.25	2	1.17	1.17	0	1.16	1.16	0
Ampco 18—S. C.	84.34	10.70	4.71	.22	.01	8	1.47	1.52	4	1.48	1.52	4	1.30	1.32	2	1.32	1.34	2
Ampco 46—S. C.	81.59	10.32	4.38	3.59	.10	4	1.25	1.26	2							1.10	1.10	2
Ampco 46—S. C.	79.58	10.38	5.33	4.66	.03	4	1.38	1.38	1							1.18	1.18	1
Ampco 46—S. C.	78.08	10.23	5.79	5.86	.02	4	1.69	1.74	6							1.32	1.35	2
Ampco 46—S. C.	79.78	10.09	4.30	5.76	.02	4	1.35	1.39	5							1.18	1.20	4
Ampco 46—S. C.	79.95	10.04	6.01	3.95	.03	4	1.43	1.45	2							1.28	1.29	0
Ampco 45—Ext.	81.25	9.90	2.98	5.12	.75	3	1.05	1.05	1				1.11	1.11	0	1.05	1.05	0
Ampco 45—Ext.	81.91	9.95	2.54	4.80	.80	3	1.03	1.03	0				1.11	1.11	0	1.04	1.04	0

Treatment A — As Cast
Treatment B — Heated to 1200°F — Quenched
Treatment C — Heated to 1650°F — Quenched
Treatment D — Heated to 1650°F — Quenched then heated to 1200°F — Air cooled

TABLE III

PROPERTIES OF COPPER-NICKEL ALLOYS

Type or Name	Specification	Condition and Treatment	Chemical Composition in %									Mechanical Properties				Hardness BHN	Normal Permeability—μ						Ideal μ H=0.5	Remarks
			Cu	Ni	Fe	Zn	Sn	Mn	Si	Pb	C	TS in PSI	YS .2% Set	Elong. % 2"	R.A. %		H=0.5			H=20	H=100	H=200		
																	−40°C	+24°C	+49°C	+24°C	+24°C	+24°C		
70:30 Cu-Ni		Wrought-Annealed	70.37	29.50	.006	<.01	<.01	.05		.003	.02					115					1.00	1.00		
70:30 Cu-Ni		Above-Cold Red. 20%	70.37	29.50	.006	<.01	<.01	.05		.003	.02										1.00	1.00		
70:30 Cu-Ni+Fe	N.D. 46C6b	Wrought-Annealed	68.09	30.86	.31	<.01	<.01	.74		<.01											1.00	1.00		
70:30 Cu-Ni+Fe	N.D. 46C6b	Wrought-Annealed	69.55	29.51	.50	<.01	<.01	.37		.003	.01					133					1.00	1.00		
70:30 Cu-Ni+Fe		Above-Cold Red. 20%	69.55	29.51	.50	<.01	<.01	.37		.003	.01										1.00	1.00		
70:30 Cu-Ni+Fe		Wrought-Annealed	67.53	30.49	.91	<.01	<.01	1.11		.005	.02					122					1.00	1.00		
70:30 Cu-Ni+Fe		Above-Cold Red. 20%	67.53	30.49	.91	<.01	<.01	1.11		.005	.02										1.00	1.00		
80:20 Cu-Ni+Fe		Cent. Cast	77.8	20.1	.82	.01	.01	.89	.48			74,500	56,700	11	19	166	2.84	1.97	1.65	1.86	1.50[2]	1.29[2]	1.96	Broken Static Torsion—μ=1.23@200H
80:20 Cu-Ni+Fe		Cent. Cast Annealed	77.8	20.1	.82	.01	.01	.89	.48												1.00	1.00		
55: +Fe		Wrought Hot Rolled	53.77	44.68	.52	None	None	1.14				71,500	30,000[1]	47.5	78.5						1.00	1.01		

NOTES: [1] Proof Stress

[2] Additional Permeability Data

μ@	
25H	1.88
50H	1.72
75H	1.60
100H	1.50

TABLE IV

MAGNETIC PROPERTIES OF 90:10 COPPER-NICKEL ALLOYS CONTAINING IRON

LOT No.	Chemical Composition %				Heat Treatment "A" [1]		Heat Treatment "B" [2]		Heat Treatment "C" [3]	
	Cu	Ni	Fe	Mn	μ @ 100 H	μ @ 200 H	μ @ 100 H	μ @ 200 H	μ @ 100 H	μ @ 200 H
A	89.67	9.98	.01	.32	1.00	1.00	1.00	1.00	1.00	1.00
B	89.20	9.99	.48	.32	1.00	1.00	1.00	1.00	1.00	1.00
C	89.00	9.95	.71	.32	1.00	1.00	1.00	1.00	1.18	1.18
D	88.75	9.97	.95	.32	1.00	1.00	1.04	1.04	1.14	1.14
E	88.48	10.00	1.19	.32	1.00	1.00	1.23	1.27	1.55	1.55
F	88.18	10.05	1.44	.32	1.00	1.00	1.23	1.28	1.82	1.83
G	87.56	10.14	1.96	.33	1.00	1.00	1.34	1.44	2.39	2.40

NOTES: [1] Heat Treatment "A"—Annealed 1 hour @ 900°C and quenched.

[2] Heat Treatment "B"—Rolled 6 B&S Nos. Hard. Then annealed 1 hour @ 900°C and quenched plus 8 hours @ 650°C air cooled.

[3] Heat Treatment "C"—Lots A to D incl.—Annealed 1 hour @ 900°C and quenched plus 2 hours @ 550°C.

Lots E to G incl.—Annealed 1 hour @ 900°C and quenched plus 2 hours @ 600°C.

permeability above .70% Fe. Heat Treatment "C," designed to develop substantially maximum precipitation hardness in quenched material, shows increases in permeability above .50% Fe. As in the case of brasses and bronzes, we find that in the absence of iron the permeability of the 90:10 cupro-nickel alloy is unaffected by treatment. Furthermore, it is apparent from Tables III and IV that the iron content does not affect the permeability of annealed cupro-nickel alloys.

MISCELLANEOUS COPPER BASE ALLOYS

The magnetic characteristics of miscellaneous copper base alloys are tabulated in Table V. All of these alloys had a permeability of 1.00 except the cast CuSi alloy which contains iron.

NICKEL BASE ALLOYS

Properties of nickel base alloys are tabulated in Table VI. As noted in the Table, considerable data has been obtained from the published literature. It is well known that Monel and "R" Monel are readily attracted by a magnet and as such have high permeabilities. It should be noted, however, that the permeabilities of the modified monels containing aluminum ("K" Monel) or silicon ("S" Monel), and Inconel containing approximately 7% Fe, are low.

Monel 326 is a new low permeability composition developed by the International Nickel Company. This alloy is similar to the standard Monel except that the Curie point has been lowered by reducing the nickel content to approximately 60%. In general the Curie point of this alloy appears to be near $-40°C$. Accordingly, the normal permeability measurements made at $-40°C$ and shown in Table VI exhibit a wide range of values.

ALUMINUM AND MAGNESIUM BASE ALLOYS

These alloys were not investigated. The literature indicates, however, that in the absence of iron all the alloys will have permeabilities comparable to that of air.

RESULTS OF TESTS ON FERROUS MATERIALS

AUSTENITIC STAINLESS STEELS—GENERAL

The metallurgy of the austenitic stainless steels is a complex subject which is covered in great detail in the literature. Consequently only those facts having a direct bearing on the magnetic properties of these steels will be pointed out here. First, let us consider two of the structural phases likely to be encountered in austenitic stainless steels. The one phase, austenite, is a solid solution of iron and other alloying elements. This phase is characterized by a face-centered cubic crystal structure which is non-magnetic and thus has a normal permeability of 1.00. The other phase, ferrite, is also a solid solution of iron and other alloying elements, but unlike austenite it has a body-centered cubic crystal structure and is strongly ferromagnetic. In ordinary plain carbon steels the magnetic constituent, austenite, is stable at high temperatures. In the case of austenitic stainless steels, sufficient amounts of alloying elements have been added to cause the austenite to be "meta-stable" at room temperature. This is a state of pseudo-equilibrium in which the austenite appears as a stable phase but has a tendency to transform into magnetic ferrite. (The term ferrite is used here for simplicity. Actually this transformation is probably to a pseudo-martensite.)

Whether the alloy is entirely austenitic and whether the tendency to transform is strong or weak is greatly influenced by the chemical composition of the alloy. Some of the alloying elements tend to promote the formation of austenite while others tend to promote the formation of ferrite. The amount of each element present in the composition, therefore, determines the ultimate structure and magnetic properties of the alloys. Among the austenite promoters are carbon, nickel, manganese, and nitrogen; while ferrite formers are chromium, silicon, molybdenum, and columbium. These alloys do not all behave with the same potency, however, so that a change in one may be far more effective than another.

The application of cold plastic deformation promotes the transformation from austenite to ferrite. The more unstable the austenite, the greater the susceptibility of the alloy to cold work. Since the stability of the austinite is directly related to composition, susceptibility to cold work also becomes a function of composition.

AUSTENITIC STAINLESS STEELS—CAST

Schoefer[2] has reported on the magnetic properties of cast stainless steels and only a brief summary of his paper will be presented here. It was mentioned previously that all alloying elements do not behave with the same

TABLE V

PROPERTIES OF MISCELLANEOUS COPPER-BASE ALLOYS

Type or Name	Specification	Condition and Treatment	Chemical Composition in %									Mechanical Properties				Hardness	Normal Permeability—μ						Ideal	Br
			Cu	Zn	Sn	Fe	Ni	Mn	Si	Be	Other	T. S. in psi	Y. S. .5% Ext.	Elong. % in 2"	R. A. %		H=0.5			H=20	H=100	H=200	μ H=0.5 +24°C	
																	−40°C	+24°C	+49°C	+24°C	+24°C	+24°C		
Cu-Be-Co Alloy	AMPCO 91-20	Extruded Soln. Quench and Aged	96.68			.02			.04	.44	Co 2.81	99,000	72,000	10.0	12.0	244 BHN					1.00	1.00		
Cu-Be-Co Alloy	AMPCO 95N-20	Cent. Cast Soln. Quench and Aged	98.84			.02	.43		.05	.23	Co .43	90,000	65,000	8.0	8.0	228 BHN					1.00	1.00		
Cu-Be-Co Alloy	AMPCO 95N-20	Extruded Soln. Quench and Aged	97.66			.05	.63	.01	.03	.21	Co 1.41	10,000	75,000	15.0	24.0	228 BHN					1.00	1.00		
Cu-Cr Alloy	AMPCO 97-20	Extruded Soln. Quench and Aged	99.26	None		.04			.02		Cr .63	78,000	55,000	15.0	15.0	80 Rb					1.00	1.00		
Cu-Be Alloy	N.D. 46C10 (INT) (AMPCO 83-20)	Extruded Soln. Quench and Aged	97.74			.03	.02	.01	.06	1.87	Co .29	176,000	121,000	8.0	17.6	321 BHN					1.00	1.00		
Cu-Be Alloy	AMPCO 86-20	Sand Cast Soln. Quench and Aged	96.12			.02	1.17			2.65		160,000	100,000	2.5	2.5	375 BHN					1.00	1.00		
Cu-Si Alloy	N.D. 46B28a	Cast	90.9	3.0	1.0	1.25		.56	3.2			49,600		9.3							1.10	1.10		
Cu-Si Alloy "Duronze"		Wrought Hard Drawn	97.2	1.96	None	.01	None	None	.83			111,300	45,600[1]	12.4	57.9		<1.02	<1.02	<1.02	<1.02	1.00	1.00	<1.02	<0.02
Cu-Si-Mn Alloy		Wrought Hard Drawn	96.25			.17		.95	2.72												1.00	1.00		

Note: (1) Proof Stress

potency in determining the stability of the austenite. For example, in the normal ranges of cast and wrought austenitic stainless alloys, the effect of each element on the microstructure can be translated into chromium or nickel equivalents in accordance with the following equations:

$$\text{Chromium equivalent} = \text{Cr\%} + 2.5\text{Si\%} + 1.8\text{Mo\%} + 2\text{Cb\%}$$

$$\text{Nickel equivalent} = \text{Ni\%} + 0.5\text{Mn\%} + 30.\text{C\%}$$

Each element is weighted with a factor which indicates its potency as a ferrite or an austenite former. As can be seen from the equations, carbon is 30 times more potent than nickel in forming austenite and molybdenum is 1.8 times more potent than chromium in forming ferrite.

Fig. 4 is a portion of the tentative constitution diagram taken from Schoefer's paper. This provides a means of determining, through the use of equivalent values, the approximate amount of ferrite that may be expected in an alloy.

The results of magnetic measurements made on cast austenitic steels are tabulated in Table VII. Some of the data are plotted on Fig. 4 in order to show where these steels lie on the tentative constitution diagram.

In examining specifications used in procuring corrosion-resisting austenitic castings, one finds that under the existing chemical composition a wide range

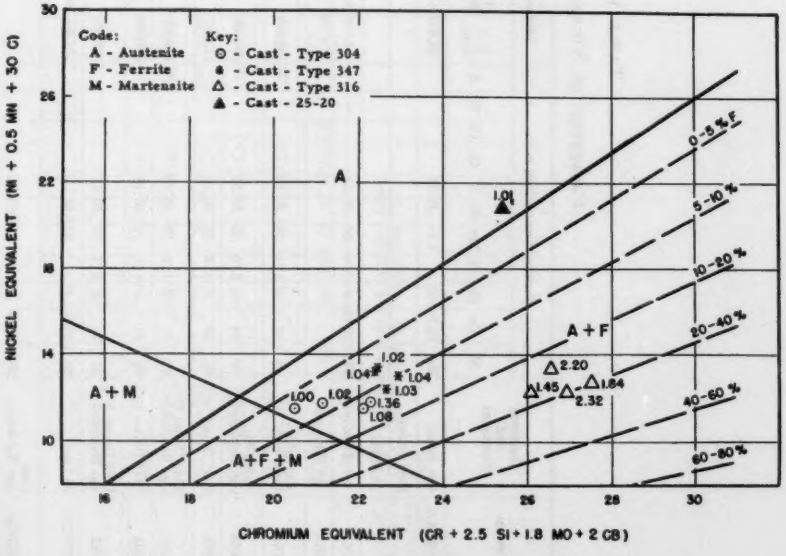

FIG. 4 TENTATIVE CONSTITUTION DIAGRAM FOR CHROMIUM-NICKEL STEELS (AFTER SCHOEFER)

TABLE VI

PROPERTIES OF NICKEL-BASE ALLOYS

Type or Name	Specification	Condition and Treatment	Chemical Composition in %											Mechanical Properties				Hardness	Normal Permeability—μ						Ideal μ H=0.5 at +24°C	iHc	Br
			Ni	Cu	Fe	Al	Mn	Si	C	Cr	Co	Ti	S	T. S. in psi	Proof Stress psi	Elong. %—2"	R.A. %		H=0.5[5]			H=20	H=100	H=200			
																			−40°C	+24°C	+40°C	+24°C	+24°C	+24°C			
Monel	N.D. 46M7gClb	Hot Rolled	Bal	29.54	2.13		1.44	.02	.18					89,800	55,300[3]	36.5	69.5						>3	>3			
"R" Monel		Cold Drawn																	9.4•	16.8•	19.0•	—			123	0.96	25.18
"R" Monel		Annealed																	30.0•	46.5•	46.2•	—			127	0.31	8.66
"K" Monel	N.D. 46N5	Age Hardened	63.79	29.63	1.04	4.89	.56	.23	.26					162,800	121,000	21.5	39.4		<1.02	<1.02	<1.02	<1.02	1.01	1.01	<1.02	—	<0.02
"K" Monel	N.D. 46N5	Age Hardened																	<1.004	<1.004	<1.004	<1.004△			1.01	25.80	0.15
"K" Monel[1]	N.D. 46N5	Annealed Quenched	66	29	.9	2.75	.75	.50	.15					92,500										1.00			
"K" Monel[1]	N.D. 46N5	Annealed Age Hardened	66	29	.9	2.75	.75	.50	.15					151,000										1.00			
"K" Monel[1]	N.D. 46N5	Cold Drawn 20%	66	29	.9	2.75	.75	.50	.15					137,000										1.00			
"K" Monel[1]	N.D. 46N5	Cold Drawn 20% Age Hardened	66	29	.9	2.75	.75	.50	.15					186,500										1.00			
"K" Monel[1]	N.D. 46N5	Cold Drawn 50%	66	29	.9	2.75	.75	.50	.15					151,250										1.00			
"K" Monel[1]	N.D. 46N5	Cold Drawn 50% Age Hardened	66	29	.9	2.75	.75	.50	.15					198,000										1.00			
"S" Monel	N.D. 46N7ClA	As Cast	66.14	28.10	1.49		.62	3.65						136,500	102,200	9.7	15.3	316 BHN					1.01	1.01			
"S" Monel	N.D. 46N7Clb	Cast Age Hardened	66.19	28.49	.25		.85	4.01	.05									33 Rc	<1.02	<1.02	<1.02	1.01	1.01	1.01	<1.02	73.72	0.88

Monel 326																		1.24	1.02	1.03*				1.02		
Monel 326																		2.89	1.01	1.05*				1.01		
Monel 326																		1.87	1.01	1.03*				1.01		
Inconel[2]		Annealed	77.0	.2	7.0		.25	.25	.08	15.0			.007	98,000									1.01			
Inconel[2]		Cold Drawn 20%	77.0	.2	7.0		.25	.25	.08	15.0			.007	129,000									1.01			
Inconel[2]		Cold Drawn 50%	77.0	.2	7.0		.25	.25	.08	15.0			.007	150,500									1.01			
Inconel[2]		Cold Drawn 50% Stress Equalized	77.0	.2	7.0		.25	.25	.08	15.0			.007	154,000									1.01			
Inconel[2]		Cold Drawn 50% Carbide Precip.	77.0	.2	7.0		.25	.25	.08	15.0			.007	100,000									1.01			
Modified Inconel		Hot Rolled Annealed	76.03		6.0	1.30	.19	.42	.03	13.05	.33	.70		106,400	45,600[4]	62.0	64.0					1.00	1.00			

Notes:
[1] Data obtained from INCO Technical Bulletin T-9 dated Dec. 1949.
[2] Data obtained from INCO Technical Bulletin T-7 dated Mar. 1950.
[3] Johnson's Limit.
[4] Yield strength (.1% set)
[5] • H=0.2
△ H≧7.0
*0°C

TABLE VII

MAGNETIC PROPERTIES OF CAST AUSTENITIC STAINLESS STEELS

CR-NI STEELS

Type or Name	Specification	Condition and Treatment	Chemical Composition in %										Mechanical Properties				Hardness	Normal Permeability—μ						Ideal		
			C	S	P	Mn	Si	Cr	Ni	Mo	Cu	Other	T.S. in psi	Y.P. in psi	Elong. %—2"	R.A. %		H=0.5			H=20	H=100	H=200	μ H=0.5	iHc	Br
																		−40°C	+24°C	+49°C	+24°C	+24°C	+24°C	+24°C		
Cast-Type 304	MIL-S-867 (Ships) Class I	Cast+ 2050°F—W.Q.	.06	.016	.013	.80	.97	18.16	9.35				69,000	34,000	68.0							1.00	1.00			
"	"	"	.07	.023	.013	.70	1.06	18.50	9.43				69,000	30,500	72.5							1.02	1.02			
"	"	"	.06	.020	.015	.72	.99	19.72	9.43				71,500	35,000	54.0			1.06	1.07	1.07	1.08	1.08	1.08	1.10	9.53	0.88
"	"	"	.07	.014	.011	.67	1.22	19.50	9.43				77,000	41,500	44.0							1.34	1.36			
Cast-Type 347	MIL-S-867 (Ships) Class II	Cast+ 2050°F—A.Q.	.08	.020	.015	.79	.75	18.94	10.20			Cb 1.03	77,000	42,500	37.0							1.04	1.04			
"	"	"	.06	.022	.019	.70	.75	18.92	11.00			Cb .70	78,000	38,000	39.0							1.04	1.04			
"	"	"	.08	.020	.013	.71	.81	18.44	10.68			Cb .97	76,000	38,000	35.0			<1.02	1.03	1.02	1.03	1.03	1.02	1.06	12.56	0.50
"	"	"	.06	.018	.015	.67	.82	18.88	10.38			Cb .84	77.500	40.000	37.0							1.03	1.03			
Cast-Type 316	MIL-S-867 (Ships) Class III	Cast+ 2050°F—W.Q.	.07	.018	.014	.70	.90	19.46	11.00	2.70			79,500	44,000	47.0							2.13	2.20			
"	"	"	.07	.029	.017	.76	1.01	19.67	10.21	2.95			80,500	45,500	52.5							1.79	1.84			
"	"	"	.06	.019	.012	.72	1.08	19.67	10.37	2.55			82,500	46,000	50.5							2.25	2.32			
"	"	"	.06	.021	.015	.74	.94	19.17	10.02	2.55			81,000	45,000	52.0			1.40	1.43	1.45	1.49	1.44	1.45	1.70	10.33	6.44
Cast 18−8+Cb	MIL-S-867 (Ships) Class I	Cast Pipe Stabilized	.06	.015	.017	.65	.83	18.82	9.03			Cb .24	71,000	28,500[1]	29.5	60.1	134 BHN	1.91	2.14	2.10	2.12	2.48	2.66	4.13	12.31	23.28
Cast-25-20		As-Cast	.08			.88	.51	24.55	20.09	.17	.08		70,000 Min.	35,000 Min.	30.0 Min.			<1.02	<1.02	<1.02	<1.02	1.01	1.01	<1.02		<0.02

CAST IRONS

Ductile Ni-Resist	As-Rec'd	total 2.98	.012	.065	1.15	2.2	2.36	20.48		Mx .085	64,500	12.5		91 Rb	1.03	<1.02	1.02	<1.02	1.02	1.03	1.19	61.42	2.11
"	Above-annealed @1150°F—1 hr.	2.98	.012	.065	1.15	2.2	2.36	20.48		Mx .085					1.03	<1.02	1.02	1.03	1.02	1.03	1.10	64.28	2.48
"	As-Rec'd annealed@1700°F 1 hr.	2.98	.012	.065	1.15	2.2	2.36	20.48		Mx .085					1.06	1.03	1.03	1.06	1.03	1.04	1.36	29.12	2.32
"	As-Rec'd Cold Red. in Ten.-8%	2.98	.012	.065	1.15	2.2	2.36	20.48		Mx .085				92 Rb					1.03	1.04			

Notes: 1 Yield strength (.2% Set)

of magnetic properties can be expected. For example, if in specification MIL-S-867 (Ships) the ferrite forming elements are on the high side, then according to Fig. 4 Class I material will be wholly austenitic while Class II and Class III materials will contain approximately 0 — 5% ferrite and 5 — 10% ferrite, respectively. On the other hand, if conditions are reversed, i.e., ferrite formers on the high side and austenite formers on the low side, Class I and II will contain approximately 40 — 60% ferrite and Class III approximately 60 — 80% ferrite.

Fig. 5 shows the relationship between normal permeability and percent ferrite as determined by the author through a carefully controlled series of permeameter and microscopic measurements. By comparing Fig. 5 with the data plotted in Fig. 4, it can be seen that the percent ferrite determined by permeability measurements is somewhat lower than that obtained from the use of the tentative constitution diagram.

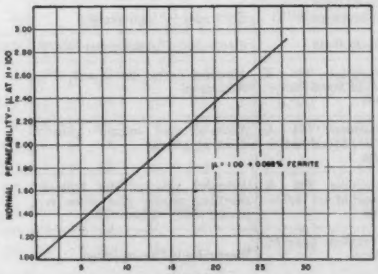

FIG 5 PERMEABILITY - % FERRITE RELATIONSHIP

AUSTENITIC STAINLESS STEELS—WELD METAL

The results of tests made on all-weld metal deposits are presented in Table VIII. In general, the metallurgical principles which apply to austenitic weld deposits are identical to those for castings. Schaeffler[3] published a paper on the metallurgical characteristics of austenitic weld deposits which shows a diagram similar to Schoefer's.

TABLE VIII

PROPERTIES OF WELD METALS

Material	Description	Normal Permeability—μ						Ideal μ H=0.5 +24C°	iHc	Br
		H=0.5			H=20	H=100	H=200			
		−40°C	+24°C	+49°C	+24°C	+24°C	+24°C			
Type 304 Elc Weld	Electrodes 1/8"-As Deposited Sigma Welded with Argon					1.00				
18-8 Cb Weld (Stainweld A5 Cb)	Electrodes 5/32"—As deposited		2.06			2.06	2.29	3.35		
18-8 Mo Welded	Electrode 1/4"—As deposited					1.00				
18-9 Elc Weld	Electrode 1/4"—As deposited					1.52				
19-9 Weld (Chromend K)	Electrodes 5/32"—As deposited		1.15			1.15	1.17	1.21		
19-9 Cb Weld (Long. weld)	Electrodes 5/32" stabilized at 1550°F	1.72	1.77	1.79	1.91	1.73	1.92	3.32	27.41	45.80
19-9 Cb Weld (Trans. weld)	Electrodes 5/32" stabilized at 1550°F					1.04	1.04			
19-9 Ti Weld	Electrodes 5/32" as deposited	1.29	1.30	1.31	1.34	1.33	1.38	1.57	32.04	19.14
18-13-2 Weld (Chromend KMo)	Electrodes 1/8" as deposited		1.05			1.02	1.02	1.22		
17-12 Mo Elc Weld	Electrode 1/4"-As deposited					1.01				
17-12 Mo-Cb Weld	Electrode 1/4"-As deposited					1.10				
29-9 Weld	Electrode 1/4"-As deposited					8.65				
25-12 Weld (Chromend HC)	Electrodes 5/32" as deposited		1.57			1.54	1.60	2.01		
25-12 Ti Weld	Electrodes 1/8" as deposited	1.05	1.07	1.07	1.07	1.08	1.09	1.09	30.36	4.01
25-20 Weld (Chromend HCN)	Electrodes 1/8" as deposited		<1.004			1.00	1.00	<1.004		
25-20 Weld	Electrodes 5/32" stabilized at 1550°F	<1.02	<1.02	<1.02	<1.02	1.00	1.00	<1.02		<0.02
Stainless 304 & Weld Metal 19:9 + 308	Annealed parent metal and 15% weld metal	1.08	1.07	1.09	1.11			1.38	55.84	16.88
Stainless 304 & Weld Metal 19:9 + 308	Annealed and sodium hydride descaling process	1.08	1.10	1.09	1.11			1.23	57.25	15.45
Stainless 304 & Weld Metal 19:9 + 308	Annealed plus sodium hydride descaling process plus stress relieving 1500°—5 hrs.—FC	1.08	1.07	1.11	1.11			1.27	16.95	2.72
Frogalloy Type M Weld	Electrodes 1/4" as deposited					1.00	1.00			

AUSTENITIC STAINLESS STEELS—WROUGHT

The results of tests on the wrought austenitic stainless steels are tabulated in Table IX. As was the case in the cast materials, the magnetic behavior of the austenitic wrought alloys is governed by their composition. However, the wrought and cast alloys differ in several respects. A stainless steel that is to be produced in the wrought form must be one that has satisfactory rolling or forging properties. Similarly a stainless steel which is to be cast must have satisfactory "castability." If one compares the composition ranges of wrought and comparable cast alloys, it is immediately apparent that the ferrite-promoting elements are held down and the austenite-promoting elements increased in the wrought alloys with respect to the cast alloys. As a result, if the nickel and chromium equivalents are calculated as before, it will be found that in general the wrought alloys will be on the border line of the wholly austenitic area of Fig. 4 whereas the cast alloys will lie within the austenite plus ferrite area. One would expect, therefore, that in the annealed condition the wrought alloys would have low permeabilities. Zapffe[4] gives a maximum normal permeability of 1.02 for *annealed* AISI Types 301, 302, 303, 304, 305, 308, 309, 310, 316, 317, 321, and 347 *wrought* alloys.

To the contrary, considerable difficulty has been experienced by various steel manufacturers in producing Type 321 stainless steel plate with acceptable permeability. An investigation made by one manufacturer several years ago on sheet products, indicated that a maximum permeability of 1.08 could be met using a standard annealing procedure. However, inconsistent and erratic permeabilities have been observed for annealed plate products, the data shown in Table X being typical of the results obtained.

The unexpected behavior of these heavier sections has not been completely explained. There are indications, however, that it is associated with the strong ferrite stabilizing tendencies of titanium.

TABLE X

COMPOSITION AND PERMEABILITY OF 9 HEATS OF TYPE 321 WROUGHT STAINLESS STEEL

Range of Thickness	Chemical Composition %										Range of Normal Permeability at +24°C 100H
	C	Mn	P	S	Si	Ni	Cr	Ti	Cu	Mo	
5/8" — 1"	.05	1.55	.037	.012	.84	9.67	17.96	.41	.31	.24	1.46—1.70
5/8"	.05	1.22	.032	.006	.77	9.83	17.35	.39	.18	.22	1.06
5/8"	.06	1.40	.040	.010	.59	9.85	17.60	.41	.32	.17	1.01—1.02
1 5/8"	.06	1.18	.033	.012	.64	10.01	17.88	.36	.27	.17	1.05
5/8" to 1 5/16"	.04	1.47	.029	.007	.81	10.12	17.68	.57	.24	.11	1.26—2.28
5/8"	.06	1.35	.028	.023	.75	10.13	18.80	.41	.24	.18	1.29
1 3/16"	.05	1.57	.030	.019	.67	10.36	17.84	.43	.23	.17	1.17—1.59
3/4"	.07	1.45	.034	.012	.39	10.42	18.44	.42	.22	.16	1.05
5/8"	.07	1.37	.033	.010	.71	10.56	17.88	.50	.34	.10	1.28

TABLE IX

PROPERTIES OF WROUGHT AUSTENITIC STAINLESS STEELS

Material	Described Condition	Chemical Composition in %											Normal Permeability—μ						Ideal μ H=0.5 at +24°C	iHc	Br
													H=0.5			H=20	H=100	H=200			
		C	S	P	Mn	Si	Cr	Ni	Mo	Cu	Al	Other	−40°C	+24°C	+49°C	+24°C	+24-C	+24°C			
Stainless Steel-AISI 302	From wire .188 x .755	.12	.013	.008	.41	.58	18.55	9.98		.09			1.35	1.36	1.36	1.41	1.38	1.66	2.40	126.6	141.0
" " " "	From wire .188 x .755												1.56	1.55	1.55	1.64	1.56	2.00	5.01	108.5	192.0
" " " "	Cut from bar stock	.061	.01	.04	.99	.40	17.60	8.00	.18	.18			1.08	1.07	1.06	1.07	1.08	1.13	1.22	156.7	36.69
" " " "	Machined from 1" bar	.075	.020	.040	.99	.41	18.73	8.03	.29	.12			1.34	1.35	1.43	1.59	1.28	1.33	2.33	13.09	12.83
" " " "	¾" bar pulled in tension reduced 28.3%	.045	.015	.020	1.25	.48	18.3	10.7	.06	.12			1.30	1.34	1.37	1.46	1.34	1.43	2.57	42.59	37.03
" " " "	¾" ϕ tension spec. reduced 30.0%	.075	.020	.040	.99	.41	18.73	8.03	.29	.12			1.94	1.91	1.97	2.04		>3.0	8.60	73.72	193.8
" " " "	Machined from 1⅝ ϕ as rec'd bar	.045	.015	.020	1.25	.48	18.3	10.7	.06	.12			1.62	1.66	1.55	1.91	1.33	1.36	3.10	5.60	8.96
" " " "	Annealed. Machine straightened & centerless ground	.074	.021	.023	1.12	.59	17.81	8.85					<1.004	<1.004	<1.004	<1.004△	1.01	1.05	1.01	306.0	1.92
" " " "	Annealed, cold drawn approximately 18%, machine straightened & stress relieved	.085	.009	.024	1.27	.66	18.38	9.35					1.04	1.04	1.04	1.04△	1.09	1.18	1.39	350.0	39.56
" " " "	Annealed, cold drawn approximately 25%, machine straightened & stress relieved	.080	.013	.027	1.22	.41	17.73	8.79					1.13	1.15	1.14	1.19	1.18	1.44	1.15	151.5	12.21
" " " "	Hot cold forged—25% cold reduction												<1.004	<1.004	<1.004	1.004△			1.01	75.53	0.70
Stainless Steel-AISI 303	Annealed 2 hours at 2000°F, water quenched												1.01	1.01	1.01	1.01△			1.23	34.00	0.13
" " " "	Annealed, machine straightened & centerless ground	.050	.259	.031	.67	.49	18.42	8.55					1.09	1.10	1.10	1.12△	1.03	1.04	1.10	204.0	79.10
" " " "	Cold drawn												<1.004	<1.004	<1.004	<1.004△			1.03	490.0	5.91
Stainless Steel-AISI 304	Cut from bar	.073	.030	.037	1.03	.47	18.87	8.47	.30	.24			<1.02	<1.02	<1.02	<1.02	1.00	1.00	<1.02	113.7	0.45
" " " "	As rec'd. Machined from 1" diam. bar, shot peened	.07			.57		18.87	9.43					<1.02	<1.02	<1.02	<1.02	1.01	1.01	1.04	170.7	1.43
" " " "	As rec'd. Machined down to ½" diam.	.075	.020	.040	.99	.41	18.73	8.03	.29	.12			1.30	1.27	1.32	1.55	1.23	1.26	2.03	10.71	9.17
" " " "	Machined from ¾" diam. after 27.9% red. by pulling	.030	.015	.017	1.32	.49	18.29	10.72	.04	.11			1.02	<1.02	<1.02	1.08	1.01	1.01	<1.02	233.0	2.40
" " " "	Tension spec. reduced 29.3%	.075	.020	.040	.99	.41	18.73	8.03	.29	.12			1.87	2.43	2.45	2.72		>3.0	24.5	58.66	432.0
" " " "	Spec. machined from 1" bar and twisted to rupture in static torsion machine as ½" diam.	.07			.57		18.87	9.43					1.07	1.02	1.07	1.06	1.08	1.12	1.22	317.4	59.30

"	"	"	"	Machined from 1⅝" ϕ as rec'd.	.030	.015	.017	1.32	.49	18.29	10.72	.04	.11			<1.02	<1.02	<1.02	<1.02	1.00	1.00	<1.02	46.20	0.15
"	"	"	"	1.008" pulled reduced diam. 23.3%, elongation 27.6%	.07			.57		18.87	9.43					<1.02	<1.02	<1.02	1.02	1.02	1.04	<1.02	154.3	8.23
"	"	"	"	Spec. machined from 1.008" bar pulled in tension. Machine reduced 37.5%, elongation 55.7%	.07			.57		18.87	9.43					1.04	1.04	1.05	1.05	1.06	1.15	1.37	166.3	40.62
"	"	"	"	Heated 1900°F 20 min. quench in water	.11	.012	.020	.62	.41	18.58	9.28	.16				<1.004	<1.004	<1.004	1.01△	1.02	1.02	1.02	17.61	0.27
"	"	"	"	"Hot" cold worked, forged from 2" ϕ to 1½" ϕ, finished. Forged to 1¼" while cooling from 1400°F to block. 1" ϕx6" specimen machined & stress relieved 2 hrs at 1075°F												<1.004	<1.004	<1.004	<1.004△			1.01	73.0	3.30
"	"	"	"	"Hot" cold rolled plus shot peening to Almen. .012/.016 A_2 & then pickled												<1.004	<1.004	<1.004	1.01△			1.01	225.0	2.21
"	"	"	"	"Hot" cold rolled plus nitriding by "Chapmanising" process												1.11	1.13	1.12	1.14△			1.34	200.0	86.10
"	"	"	"	As received												1.20	1.19	1.21	1.29△			1.60	19.69	10.48
"	"	"	"	Anneal—atmosphere controlled furnace at 1900°F for 1 hr—cooled in air												1.04	1.05	1.05	1.05△			1.10	15.87	11.99
"	"	"	"	Annealed, open fire at 1900°F for 1 hr, water quenched & sodium hydride descale at 750°F for 15 min.												1.08	1.08	1.09	1.10△			1.17	12.33	16.17
"	"	"	"	Mill annealed												1.02	1.02	1.02	1.02△			1.02	15.27	2.98
"	"	"	"	Mill annealed, stress relieved at 1500°F, 5 hrs-F.C.												1.02	1.02	1.01	1.02△			1.02	55.44	1.65
"	"	"	"	Mill annealed												<1.004	<1.004	<1.004	<1.004△			<1.004	21.29	0.92
"	"	"	"	Mill annealed, stress relieved 1500°F, 5 hrs-F.C.												1.03	1.03	1.04	1.04△			1.13	56.37	5.64
"	"	"	"	Mill annealed												1.51	1.72	1.77	—			2.87	12.05	13.01
"	"	"	"	Mill annealed, stress relieved at 1500°F, 5 hrs-F.C.												1.33	1.39	1.41	1.44△			2.28	37.20	33.41
"	"	"	"	Forged and annealed												<1.02	<1.02	<1.02	<1.02△	1.01	1.01	1.05	57.65	1.58
"	"	"	"	Forged, annealed, strain relieved 1500°F, 5 hrs-F.C.												1.04	1.06	1.05	1.04△	1.01	1.01	1.14	48.77	4.28
"	"	"	"	Forged, annealed												<1.02	<1.02	<1.02	<1.02△	1.01	1.01	1.04	57.25	0.64
"	"	"	"	Forged, annealed, strain relieved at 1500°F, 5 hrs-F.C.												<1.02	<1.02	<1.02	<1.02△	1.01	1.01	1.47	52.27	1.48
Stainless Steel-AISI 305				Annealed, bumper straightened	.060	.014	.028	.58	.52	18.27	11.24					<1.02	<1.02	<1.02	<1.02	1.00	1.00	<1.02	—	<0.02
Stainless Steel-AISI 309				Annealed, machine straightened & centerless ground	.068	.006	.027	2.17	.18	24.40	13.65					2.73	3.70	3.72	—	2.47	2.56	10.8	5.93	0.31
Stainless Steel-AISI 310				Annealed, machine straightened & centerless ground	.056	.009	.023	1.42	.41	24.90	20.24					<1.004	<1.004	<1.004	<1.004△	1.00	1.00	<1.004		<0.02
Stainless Steel-AISI 316				Heated 1900°F, 20 min quench in water	.11	trace	.015	1.88	.42	17.20	12.75	2.25				<1.004	<1.004	1.004	<1.004△	1.00	1.00	<1.004	sample destroyed	

TABLE IX (Cont.)

Material	Described Condition	Chemical Composition in %											Normal Permeability—μ						Ideal	iHc	Br
													H=0.5			H=20	H=100	H=200	μ H=0.5 at +24°C		
		C	S	P	Mn	Si	Cr	Ni	Mo	Cu	Al	Other	−40°C	+24°C	+49°C	+24°C	+24-C	+24°C			
Stainless Steel-AISI 316	As received												<1.02	<1.02			1.00	1.00	<1.02		
" " " "	As received, specimen turned to 0.622" and pulled in tension, cold reduced 26%												<1.02	<1.02			1.00	1.00	<1.02		
" " " "	Nitrided												1.16	1.15	1.15	1.19△			1.28	135.3	57.03
Stainless Steel-AISI 321	Nitrided												1.34	1.37	1.38	1.44△			2.05	71.70	63.15
" " " "	Heat 60966, annealed and pickled												1.20	1.22	1.24	1.29	1.18	1.20	1.55	12.40	5.71
Stainless Steel-AISI 347	Wrought pipe stabilized at 1500°F	.08	.010	.02	1.69	.39	18.13	12.34				Cb .80	<1.02	<1.02	<1.02	<1.02	1.00	1.00	<1.02		<0.02
" " " "	Bar nitrided												<1.02	<1.02	<1.02	<1.02			<1.02	16.86	0.15
" " " "	Nitrided—Cb & Ta stabilized												1.19	1.19	1.19	1.21△			1.24	143.7	72.56
Cyclops 19-9 DL	"Hot" cold forged—25% cold reduction												1.02	1.04	1.03	1.03△			1.05	29.73	1.29
Timken 16-25-6	"Hot" cold forged—25% cold reduction												1.01	<1.004	<1.004	1.004△			1.01		<0.02
Discaloy	Machined from ¾" bar, heat treated completely, bar marked D30 14D	.05			.70	.70	13.0	25.0	3.00		.2	Ti 1.80	<1.02	<1.02	<1.02	<1.02	1.00	1.01	<1.02		<0.02
"	Spec. machined from tension specimen ⅝" diam. after being reduced 12.3%	.05			.70	.70	13.0	25.0	3.00		.2	Ti 1.80	<1.02	<1.02	<1.02	<1.02		1.01	<1.02		<0.02
Thermalloy 30	As received												<1.004	<1.004	<1.004	<1.004△	1.00	1.00	1.01	51.83	0.20
Thompson Alloy	Nitrided												1.11	1.11	1.10	1.13△			1.40	94.80	29.64
17-4-6	Hot rolled	.12	.015	.020	6.00	.28	16.68	4.04									1.00	1.00			
17-4-6	Annealed	.12	.015	.020	6.00	.28	16.68	4.04									1.00	1.00			
16-16-1	As received	.10	.008	.023	16.25	.46	15.48	1.00									1.00	1.00			

△H≅7.0

This behavior occurs in two ways. First, titanium combines with carbon and nitrogen to form carbides, nitrides, and carbonitrides. In so doing, it removes these two very strong austenite stabilizers from solution and this indirectly promotes the formation of ferrite, the magnetic phase. Second, titanium in excess of that required to combine with the carbon and nitrogen present reduces the size of the gamma loop and thus tends to promote directly the formation of ferrite.

Magnetic examination with the permeability indicator of samples submitted by various manufacturers has revealed that heavy Type 321 steel plates are heterogeneous. Large variations in permeability have been observed not only between surface and center, but also between adjacent specimens. In general, the steel manufacturers have found that primary dendritic ferrite which forms during solidification of the ingot, is not removed by subsequent hot working and ordinary annealing. Annealing at 1900°F for 15 hours reduces the permeability markedly, but is not practicable in so far as mill production is concerned.

As mentioned previously, the stability of the austenite determines the susceptibility of austenitic stainless steels to cold work. Post and Eberly[5] present permeability results for a variety of stainless steels. This paper clearly points out the wide difference in response to cold work of metastable compositions such as Type 304. The literature also indicates that the permeability of wrought austenitic stainless steels should not be adversely affected by hot working operations provided the steels are not heated above nor worked below their recommended temperature ranges. The effect of various heat treatments on the normal permeability of Type 302, 321, and 347 steels is included in Table IX. It should be noted that neither slow cooling from 1950°F, nor stabilizing at 1700°F caused an increase in permeability.

Early in the investigation some preliminary work was done to determine the effect of fabrication processes such as shearing and bending on the per-

TABLE XI

EFFECT OF VARIOUS COLD WORKING TREATMENTS ON THE PERMEABILITY OF AISI TYPE 304 STAINLESS STEEL

Thickness of Sheet	Composition %			Normal Permeability — μ = 200H					
				Cond. 1	Cond. 2	Cond. 3	Cond. 4	Cond. 5	Cond. 6
	C	Cr	Ni	Annealed 1950 F W.Q. and Pickle	As rec'd and two sheared edges	Cond. 1 and 90 Longitudinal bend	Cond. 1 and 11% cold Reduction	Cond. 1 and 20% cold Reduction	Cond. 1 and 37% cold Reduction
.030"	.06	17.50	9.46	1.004	1.007	1.011			
.050"	.08	18.07	8.53	1.002	1.013	1.026	1.020	1.127	2.353
.060"	.07	19.02	9.11	1.005	1.015	1.033			

meability of Type 304 sheet stock. The results of these few tests are tabulated in Table XI. It is interesting to note that neither shearing nor 90° bending caused any marked increase in permeability. The over-all effect here is a mass effect dependent upon the proportion of worked to unworked metal.

In addition to the foregoing, permeability measurements were made on the type 304 sheet after annealing but before pickling. A considerable portion of the scale on these samples remained intact. The permeability of these samples was approximately 1.2 and indicates the necessity of removing the scale from austenitic stainless steel surfaces and welds when low permeability is required.

The substitution of manganese, either in whole or in part for the nickel normally used in austenitic stainless steels, was investigated in World War II both in this country and abroad. These alloys never gained widespread acceptance mainly because of their inferior corrosion resistance. In view of the critical shortage of nickel, these alloys are again being considered and marketed. Permeability measurements on 17% Cr – 4% Ni – 6% Mn steel and 16% Cr – 16% Mn – 1% Ni steel have been included in Table IX. The corrosion resistance of the latter alloy is reportedly similar to the standard 18% Cr – 8% Ni steels.

PRECIPITATION HARDENING STAINLESS STEELS

Permeability data on the precipitation hardening stainless steels are tabulated in Table XII. The mechanism of hardening in these steels is quite complex and not too well understood. In general, hardening is brought about in one of three ways. First, an alloying element is added to the steel which has a varying solubility in austenite. By proper heat treatment, it is possible to precipitate a non-magnetic element, phase, or compound as the hardening agent and still retain an austenitic matrix. In the second method, the added element has a higher solubility in austenite, the non-magnetic phase, than it does in ferrite, the magnetic phase. It is possible, by suitable heat treatment, to make the steel entirely austenitic and then to partially transform this phase to ferrite with subsequent precipitation of the hardening phase. In the third method, the annealed structure consists of a mixture of austenite and ferrite. Through heat treatment, the ferrite and part of the austenite is transformed to a hard, brittle, non-magnetic phase called sigma. Strictly speaking the latter method of hardening is not of the precipitation or dissolution type.

Only those steels utilizing the first mentioned mechanism wherein the austenite is retained will give consistently low permeabilities. The second described method involves the formation of magnetic ferrite and unless closely controlled, the permeability of the hardened alloy will be both high and variable. The 17 – 4 PH, 17 – 7 PH, and AISI 322 steels are of this type. It is unfortunate also that the ferrite is not always completely transformed to non-magnetic sigma phase during the third mentioned hardening procedure. Such is the case for the AISI 329 steel.

In general, the precipitation hardening stainless steels constitute a group of materials whose use must be advised with extreme caution, as delicate control of analysis and heat treatment are required to remain with low permeability limits.

TABLE XII

MAGNETIC PROPERTIES OF PRECIPITATION HARDENING STAINLESS STEELS

Material	Described Condition	NORMAL PERMEABILITY—μ						Ideal H=0.5 at +24°C	$_iH_c$	Br
		H=0.5			H=20	H=100	H=200			
		−40°C	+24°C	+49°C	+24°C	+24°C	+24°C			
17 Cr—4 Ni—PH	Wrought—950°F—2 hours—air cooled	30.0	29.5	28.5		>3.00	>3.00	150	29.45	666.7
17 Cr—7 Ni—PH	Wrought—1400°F—2 hrs—air-cool—reheat—950°F—2 hrs—aircool	21.4	21.5	23.0		>3.00	>3.00	407	31.74	690.7
Stainless Steel—AISI322	Wrought—1000°F—2 hours—air cooled	39.0	39.0	38.0		>3.00	>3.00	301	22.10	497.9
Crucible 3003	Hot rolled	1.02	1.02					1.02		
Crucible 3003	2250°F—½ hr—water—reheat—1300°F—50 hrs—furnace—40 Rc	3.97	1.62	4.00				1.91		
Resistal 3311	Hot forged or rolled	1.01	1.02	1.01	1.02			1.02	114.7	3.06
Resistal 3311	2200°F—½ hr—water—reheat—1200°F—16 hrs—furnace—35 Rc	1.01	1.02	1.004				1.02		
Resistal 3329	Annealed—hot rolled	10.9	14.2	15.3				54.9	9.00	164.6
Resistal 3329	1400°F—4 hrs—furnace—36 Rc	1.48	1.02	1.04				1.36		
Armco 21-4 Mn-S	Cold drawn	<1.004	<1.004	<1.004	△ <1.004			<1.004	91.60	0.70
Armco 21-4 Mn-S	Heat treatment—2100°F—half hr soak—water quench—age—1350°F—10 hours	1.02	1.02	1.02	△ 1.02			1.06	48.21	2.40
Armco 21-4 Mn-S	Hot rolled—1350°F—10 hours—WQ—29 Rc		<1.004			1.00	1.00	<1.004		
Armco 21-4 Mn-S-N	Cold drawn	<1.004	<1.004	<1.004	△ <1.004			<1.004	28.12	0.06
Armco 21-4 Mn-S-N	Heat treatment—2100°F—half hr soak—water quench—age—1350°F—10 hrs	<1.004	<1.004	<1.004	△ <1.004			<1.004	32.54	0.17
Special Cr-Ni-P	Hot rolled +2050°F—30 min—water quench +1300°F—24 hrs—water quench	<1.02	<1.02	<1.02	<1.02			<1.02	57.25	0.28
Special Cr-Ni-P	Hot rolled (not annealed) heated 1300°F—24 hrs—WQ—29 Rc		<1.004			1.00	1.00	<1.004		
Stainless Steel AISI329	Hot rolled—annealed 1800°F—30 min in WQ—1400°F—50 hrs WQ—36 Rc		8.00			>3.00	>3.00	18.0		

△ H≅7

AUSTENITIC MANGANESE STEELS

For applications where the superior corrosion resistance on non-magnetic stainless steels is not required, efforts have been made to utilize the austenitic manganese or so-called Hadfield steels. This substitution conserved chromium and nickel at the expense of a greater amount of manganese.

TABLE XIII

MAGNETIC PROPERTIES OF AUSTENITIC MANGANESE STEELS

Material	Described Condition	NORMAL PERMEABILITY—μ						Ideal μ H=0.5 at	iHc	Br
		H=0.5			H=20	H=100	H=200			
		−40°C	+24°C	+49°C	+24°C	+24°C	+24°C	+24°C		
Hadfield Man. Steel (1% C, 13% Mn)	Annealed at 1950°F—½ hr—water quenched	<1.02	<1.02	<1.02	<1.02	1.00	1.00	<1.02	4.06	0.10
Hadfield Man. Steel (1% C, 13% Mn)	As received	<1.02	<1.02			1.00	1.00	<1.02		
Hadfield Man. Steel (1% C, 13% Mn)	As received—specimen turned to 0.622" and pulled in tension—cold reduced 26%	1.02	<1.02			1.01	1.01	<1.02		
*Hadfield Man. Steel (1% C, 13% Mn)	Cast—As received	1.36	1.35	1.36	△ 1.39	1.00	1.00	2.71	51.22	52.00
Jessop #9 (.4% C, 13% Mn, 3.5% Ni, 4% Cr)	As received					1.00	1.00			
Jessop #9 (.4% C, 13% Mn, 3.5% Ni, 4% Cr)	Cold reduced in tension 15%					1.04	1.07			
Jessop #9 (.4% C, 13% Mn, 3.5% Ni, 4% Cr)	Machined from 1" diam. bar	<1.02	<1.02	<1.02	1.05	1.00	1.00	<1.02	70 31	0.14
Jessop #9 (.4% C, 13% Mn, 3.5% Ni, 4% Cr)	Spec. machined from ¾" diam after tension reduction of 31.1%	1.08	1 08	1.09	1.10	1 13	1.32	1.14	204 9	108.3
Mn-Ni Steel (.7% C, 14% Mn, 3% Ni)	As received with scale	1.01	1.01	1.01	△ 1.01	1.00	1.00	1.01	105.0	3.04
Mn-Ni Steel (.8% C, 14% Mn, 4% Ni)	As received with scale	<1.004	<1.004	<1.004	△ 1.01	1.00	1.00	<1.004	124.4	1.15
Jessop #200 (.3% C, 11% Mn, 7% Ni)	Pulled in tension 11% reduction in area	<1.02	<1.02	<1.02	<1.02	1.00	1.00	<1.02	26.98	0.15
Jessop #200 (.3% C, 11% Mn, 7% Ni)	Machined from ⅝" bar	<1.02	<1.02	<1.02	<1.02	1.00	1.00	<1.02		<0.02
Mn-Ni Steel (.3% C, 11% Mn, 8% Ni)	Natural finish (hot rolled)	<1.004	<1.004	<1.004	△ <1.004	1.00	1.00	<1.004	2.73	<0.02
*Cromanal (1.1% C, 12% Mn, 2% Cr)	Cast—As received	1.32	1.31	1.31	△ 1.34	1.00	1.00	2.29	53.03	30.50
Midvale Non-mag. (.7% C, 8% Mn, 9% Ni, 4% Cr)	As received—cold worked	<1.004	<1.004	<1.004		1.00	1.00	<1.004		

△ H≅7.0 * See Text

From the physical metallurgy standpoint the behavior of the austenitic manganese steels is similar to that of the austenitic stainless steels. As before, the austenite is stabilized at room temperature by the addition of alloying elements. The orginal Hadfield steels contained C and Mn as the principal alloying elements. Many modifications of the original alloy have been developed and include the addition of Cr, Ni, Mo, and V. In general, the high manganese steels are readily hot worked and lend themselves to hot rolling, drop forging, and other hot forming operations. On the other hand, these steels are extremely difficult to saw, drill or machine in the cold condition and are therefore generally unsuitable where such operations are required. However,

TABLE XIV

COMPARISON OF EFFECTS OF IDEALIZATION AND MECHANICAL VIBRATIONS IN A MAGNETIC FIELD ON PERMEABILITY AT H = 0.5 OERSTED

Material	Permeability at H = 0.5 oersted at +24°C		
	Normal	Mechanical* Vibration	Ideal**
AISI 320—Wrought	1.77	2.03	3.10
AISI 302—Cold Reduced 30%	2.02	2.05	7.76
AISI 302—Cold Reduced	1.38	1.47	2.40
AISI 302—Cold Reduced	1.43	1.66	3.51
AISI 302—Wrought	1.39	1.51	2.33
AISI 320—Cold Reduced 28%	1.36	1.42	2.57
AISI 304—Wrought	1.36	1.51	2.03
19-9 CB—Weld Metal	1.86	1.92	3.32

* At approximately 10,000-15,000 psi and 23 cps

** From 50 oersteds a-c peak

the addition of nickel appears to improve the machinability of these alloys.

The properties of the cast and wrought steels have been tabulated in Table XIII. Attention is called to the two alloys which have been noted by asterisks (*) in Table XIV. Both alloys were supplied in the form of 1" diameter cast bars. It is not unusual for cast and heat treated austenitic manganese steels to have a "skin" of highly magnetic material on the surface. It has not been definitely established whether this condition is predominantly due to the formation of martensite through decarburization or to the formation of deeply imbedded magnetic iron oxide. In any event, the apparent discrepencies in results are due to the fact that the weak field tests were made with the skin intact whereas the strong field measurements were made with the skin removed.

SUPPLEMENTARY INFORMATION

In addition to the permeability measurements shown in the tables, the Naval Ordnance Laboratory conducted two supplementary investigations. One investigation determined the effect of varying the amplitude of the diminishing a-c field on the ideal permeability, and the other determined the effect of mechanical vibration on permeability.

The results of varying the amplitude of the diminishing a-c field on five

samples are shown in Fig. 6. The data indicate that the ideal permeability increases with increasing amplitude, and that some of the alloys are completely idealized by as little as 15 oersteds, while others are still incompletely idealized at 50 oersteds.

In order to compare the effects of idealization and mechanical shaking on permeability at 0.5 oersted, eight samples which exhibited ideal permeabilities greater than two, were vibrated mechanically along their axes at stresses of the order of 10,000 psi at a rate of 23 cycles per second while in a 0.5 oersted field. Table XIV shows the results of this test. The data indicate that permeability is increased by mechanical vibration, but the effects are small as compared with the effects of idealization.

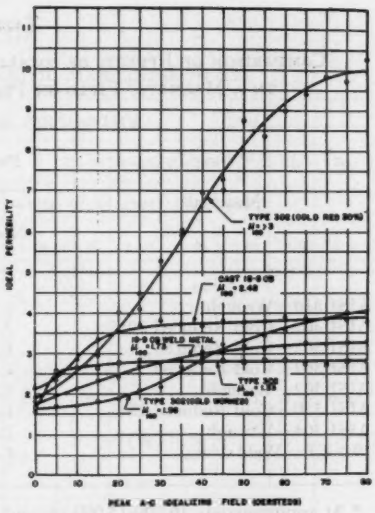

FIG. 6 IDEAL PERMEABILITY AT H=0.5 OE. AS A FUNCTION OF AMPLITUDE OF IDEALIZING FIELD

SUMMARY

The foregoing data can be summarized only in a general way inasmuch as the magnetic properties of many materials are structure sensitive. Accordingly, the normal and ideal permeabilities respond with various degrees to such factors as chemical composition, heat treatment, heterogeneity, etc.

The simplest method of summarizing the data appears to be the classification of materials into groups which typify their magnetic behavior. These are as follow:

Group I. Those materials which have normal and ideal permeabilities comparable to that of air ($\mu = 1.00$).

(a) All as-cast, annealed, or cold worked brasses, bronzes, cupro-nickel and other copper-base alloys containing less than 0.20% iron.

(b) All *fully annealed* brasses, bronzes, cupro-nickel, and other copper-base alloys containing iron in excess of 0.20% but less than 6%.

(c) Nickel-base alloys of the following types: "K" monel, "S" monel, inconel, and monel 326.

(d) Unannealed 25Cr — 20 Ni austenitic stainless steel in the form of castings, weld metal or wrought material.

(e) *Fully annealed wrought* austenitic stainless steels of the following types: 302, 303, 304, 305, 308, 309, 310, 316, 321 sheet, 347, 17Cr — 4Ni — 6Mn, and 16 Cr — 17-Mn — 1Ni.

(f) *Fully annealed* austenitic manganese-nickel steels similar to Jessop No. 9, Jessop No. 200, Taylor Wharton Mn-Ni, American Brake Shoe Nn-Ni, Crucible Mn-Ni and Midvale Non-Magnetic.

(g) Precipitation hardening stainless steels similar to Rezistal 3311, Armco 21-4 MnS, Armco 21-4 Mn-S-N, Armco Special Cr-Ni-P, Crucible HNM.

(h) All cast and wrought aluminum and magnesium base alloys except possibly those containing iron as an alloying element.

Group II. Those materials whose normal and/or ideal permeabilities may be greater than 1.00 but less than 2.

(a) All brasses and bronzes containing 6% or less of iron whether as-cast, hot rolled, cold rolled, or annealed.

(b) All cupro-nickel alloys containing 0.60% or less iron in the as-cast, hot rolled, cold rolled, or hardened condition.

(c) Austenitic cast irons such as Ni-resist Type 2.

(d) Commercial annealed, pickled, and straightened; or cold formed or unannealed but scale free hot worked wrought austenitic stainless steels Types 305 and 310.

(e) Cold formed types 305 and 310 wrought austenitic stainless steels.

(f) *Fully annealed,* "skin free" plain Hadfield and manganese-chromium austenitic steels.

(g) Weld metals of the following types: 18-8Mo, 17-12Mo, 17-12Mo-X-LoCar, 17-12Mo-Cb.

Group III. Those materials whose normal and/or ideal permeability, because of composition range or treatment, may be greater or less than 2.

(a) Commercial annealed, pickled, and straightened; or unannealed but scale free hot worked wrought austenitic stainless steels of the following types: 302, 303, 304, 316, 321, and 347.

(b) Unannealed cupro-nickel alloys containing more than 0.60% iron.

(c) Austenitic stainless steel castings.

(d) Austenitic stainless steel weld metal such as 19-9, 22-12, 18-9 X-Lo-Car, and 18-9Cb.

(e) Cold worked wrought austenitic stainless steels of the following types: 301, 302, 303, 304, 308, 309, 316, 321 and 347.

(f) As-cast or cold worked plain Hadfield manganese steels.

(g) As-cast and/or heat treated with "skin" intact austenitic manganese steels.

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MECHANICAL PUMPS FOR HIGH-TEMPERATURE LIQUID METAL

ACKNOWLEDGMENT

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INTRODUCTION

As a part of the development of nuclear power for submarine propulsion, the author's company designed and built a relatively large heat-transfer test system in which liquid sodium and liquid sodium-potassium were used as heat-transfer media. For this system it was necessary to develop a pump capable of circulating approximately 400 gpm of liquid metal at temperatures up to 750 F and which could tolerate no leakage of liquid metal at the shaft. However, a very small gas leakage was acceptable. Two identical centrifugal pumps were built and both have operated successfully for several thousands of hours.

The design of a suitable pump to circulate liquid metal was complicated by lack of information on liquid-metal corrosion, bearing operation in liquid metal, and high-temperature seals. A design study produced a centrifugal pump with a long overhung shaft and a shaft seal.* By this means the problem of bearing operation in liquid metal could be eliminated. To the best of our knowledge, type-347 stainless steel and pure nickel would be sufficiently resistant to corrosion for use on those parts in contact with liquid metal.

The extreme purity requirements of an alkali-metal system made the seal problem the most difficult to solve. The leakage of liquid metal out of the pump had to be absolutely zero. Gas leakage out of the pump and seal gas leakage into the pump had to be kept to a minimum. Even though the inert gas used to blanket the system has a high degree of purity, large quantities passed over the liquid surface would cause oxygen contamination and the cost of maintaining the blanket would be prohibitive.

The detailed design was worked out in cooperation with the Buffalo Pump Company of North Tonawanda, N. Y., where the two pumps were subsequently built. A seal-development program was carried on concurrently with the manufacture of the pumps.

* Electromagnetic pump development was in progress during this design study and the use of electromagnetic pumps was considered for this application. However, experience was limited to very small-capacity pumps. Consequently, the mechanical pump appeared more readily applicable on a short-range basis.

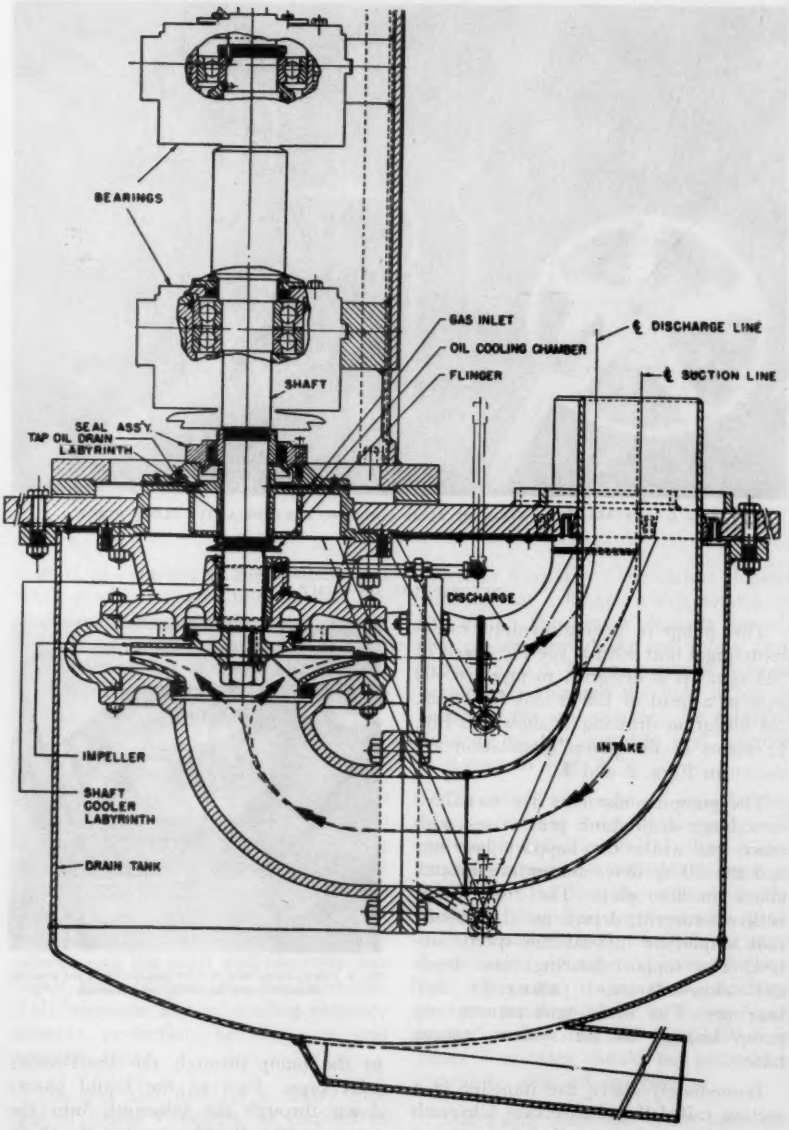

FIG. 1 SECTION THROUGH ALPLAUS MECHANICAL PUMP FOR GENIE HEAT-TRANSFER SYSTEM; 400 GPM, 126 FT HEAD

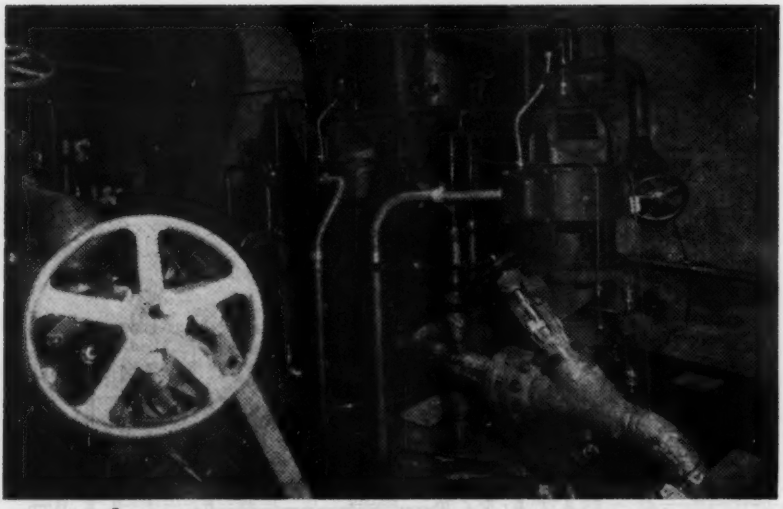

FIG. 2 INSTALLATION VIEW OF PUMP SHOWING PORTION ABOVE FLOOR PLATE

DESCRIPTION OF PUMP

The pump is a single-volute radial centrifugal unit with a specific speed of 926 rpm. It is designed to produce 400 gpm at a head of 126 ft and 1750 rpm. An elevation drawing is shown in Fig. 1; views of the pump installation are shown in Figs. 2 and 3.

The pumping elements are contained in a large drain tank pressurized with inert gas while the support bearings and the 20-hp drive motor are located above the floor plate. The drive motor is direct-current, driven by a high-current amplidyne for variable-speed control. The support bearings are standard close-tolerance (a.b.e.c.-7) ball bearings. The drain tank returns any pump leakage to the system storage tank.

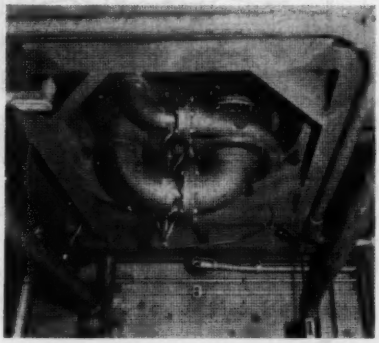

FIG. 3 INSTALLATION VIEW OF PUMP LOOKING UP AT THE PUMPING ELEMENTS WITH THE DRAIN TANK REMOVED

Immediately above the impeller is a section called the shaft-cooler labyrinth where the shaft is cooled by pumped fluid. Liquid metal is taken from the discharge side of the pump, passed through a heat exchanger, and returned to the pump through the shaft-cooler inlet pipe. Part of the liquid passes down through the labyrinth into the pump suction thereby cooling the shaft. The remainder spills over the top of the bushing and down into the drain tank. This leakage, which amounts to about

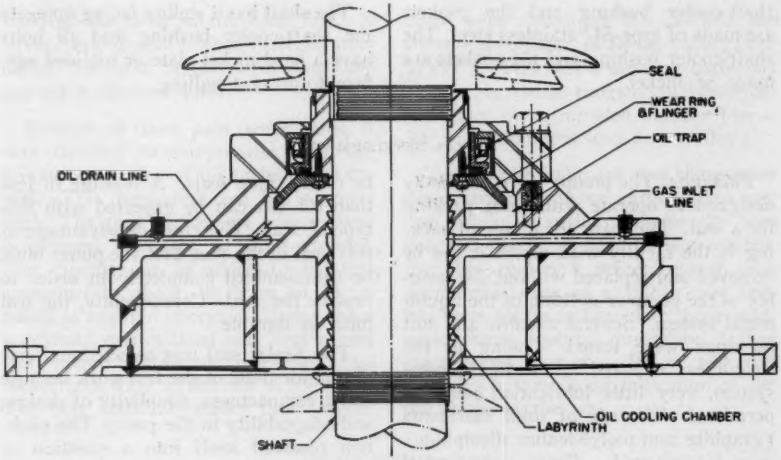

FIG. 4 SEAL ADAPTER

1 gpm, is returned to the system by a small electromagnetic filler pump. The shaft-cooler labyrinth then acts to cool the shaft and form the primary liquid seal limiting liquid-metal leakage and preventing gas leakage into the pump suction.

A second labyrinth is mounted above the shaft-cooler labyrinth and separated from it by a flinger to prevent liquid from passing up the shaft. The second labyrinth is cooled by an oil jacket which surrounds it. A gas bleed of about ½ cfm is fed into the labyrinth to sweep down liquid-metal vapors that diffuse into it. The oil-cooling chamber acts to cool the shaft and condense any vapor that diffuses into the labyrinth. This labyrinth and oil-cooling chamber provide protection for the gas seal mounted above.

The gas seal itself is a rotary face seal of Sealol ** design. It consists of a stationary carbon element and secondary silicone rubber packing which provides for flexibility. The carbon element runs against a flinger which rotates on the shaft. The flinger deposits any oil that passes through the seal into a trap provided for it. This trap may be drained periodically through the hole which is shown in the seal adapter. An enlarged drawing of the complete seal adapter is shown in Fig. 4.

The shaft is designed considerably oversize so that the long overhang will not cause deflection in the shaft-cooler bushing where the radial clearance is 0.0055 in. Further, the stresses in the shaft and impeller are kept to a minimum so that the pump will not be damaged due to short-period over-temperature operation. It has been calculated that the pump will heat up due to "egg-beater" action from 725 F to 1500 F in about 3 minutes should the pump discharge be shut off completely.

The pump shaft, the drain tank, the floor plate, and all the parts within the drain tank with the exception of the

** Sealol Corporation, Providence, R. I.

shaft-cooler bushing and the gaskets are made of type-347 stainless steel. The shaft-cooler bushing and the gaskets are made of nickel.

The shaft has a stellite facing opposite the shaft-cooler bushing and all bolts have a hard nickel-plate or nitrided surface to prevent galling.

SEAL DEVELOPMENT

Packings. The pumps were originally designed to operate with shaft packing for a seal. The main advantage of packing is the facility with which it can be removed and replaced without disassembly of the pump or opening of the liquid-metal system. Several metallic and soft packings were tested. Owing to the cleanliness required in the liquid-metal system, very little lubrication could be permitted. The use of solid lubricants (graphite and molybdenum disulphide) was investigated. Since only small quantities could be added to the packing, the effectiveness of solid lubricants was limited to the period that the lubricant would remain impregnated in the packing or held between the shaft and packing. Liquid lubricants remained for shorter periods and quickly oxidized or vaporized making them totally undesirable. Essentially, then, the packings had to run dry. Operating periods were limited to the length of time that lubricant remained in the packing plus a short period of dry operation (with associated high torque and leakage) until the packing seized the shaft. Soft packings (generally asbestos with various binders and impregnants) operated somewhat more successfully and provided lower leakage rates but failed in the absence of lubrication. Leakage rates for packings in all combinations generally were in excess of 10 standard cu ft per hr at a pressure of 15 psig. The set limit for the liquid-metal systems was less than 1 standard cu ft per hr of gas. The packing life during the tests was limited to a maximum of about 100 hr.

Rotary Face Seals. Considerable improvement in the leakage rate was obtained when the development switched to rotary face seals. A leakage of less than 0.1 cfh can be expected with this type of seal. The chief disadvantage of this seal is the fact that the pump must be disassembled completely in order to replace the seal. Consequently, the seal must be durable.

The Sealol seal was selected and employed for most of the test work because of its compactness, simplicity of design, and adaptability to the pump. The problem resolved itself into a question of carbon durability and compatibility between the stationary carbon element and the revolving seal ring or flinger on the shaft. In order to effect the low leakage rates mentioned, it was found necessary to lap both the carbon and wear-ring surfaces very flat. All rings were lapped to less than three light bands and in most cases less than one. A good surface finish also is required. Most of the wear rings averaged about 1 microinch surface roughness. A surface measuring over 2 microinches was rejected. Both these conditions were accomplished by the use of a diamond-grit-impregnated lapping plate (the diamond grit is pushed into the surface of the lapping plate and the excess wiped off. By this means no abrasive particles are transferred to the piece being lapped). Any loose abrasive-lapping process resulted in abrasive-particle penetration of the metal wear ring or carbon-seal element, thereby causing a lapping action during seal operation. For soft materials and cast iron the loose abrasive-lapping methods resulted in short seal lives.

Face seals under test operated from 45 hr to 1332 hr in a dry condition before failure. Test runs generally were continued up to a maximum of 250 hr and then the life of the seal extrapo-

lated on the basis of the wear rate. A silver-impregnated carbon material produced the best results operating dry against a nitrided surface.

Because of these poor wear rates, it was decided to compromise and use minute quantities of oil to lubricate the seal. This improved seal life a great deal. The trap in the seal adapter was considered adequate if kept drained. The quantity of oil added to the seal amounted to about 30 drops in 24 hr added at regular intervals. Under these conditions extrapolated seal lives varied from about 1000 hr to "indefinite" (no measurable wear at the end of the run). The best materials under these conditions were Graphitar No. 39 and the silver-impregnated material (Morganite MY1F). The best wear-ring materials were a hardened tungsten-molybdenum tool steel or a nitrided surface (on a 300 series stainless steel or nitralloy).

Test results indicated that there were discrepancies in wear rates within any one grade of carbon despite the fact that the exact test conditions prevailed. For this reason a screening-test program, consisting of a 100-hr test run, has been set up to eliminate those seals which have doubtful durability. It has been found that this 100-hr test run provides a very good indication of the durability of the seal.

PUMP OPERATION

After the manufacture of the pumps was completed, water tests were run to determine the pump characteristics. The results of these tests are shown in Fig. 5. A comparison of water and sodium-potassium data is shown in Fig. 6. The sodium-potassium data compare favorably with the water data. The slight discrepancies shown are within the accuracy of the instrumentation on the sodium-potassium system. Characteristic data at 1750 rpm were unobserved because of pressure-gage limitations. Characteristic data on the sodium sys-

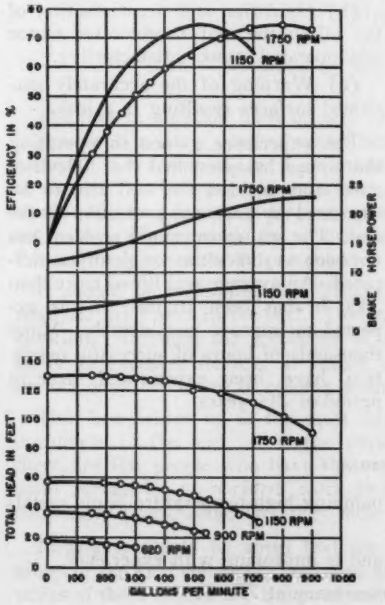

FIG. 5 WATER-TEST RESULTS

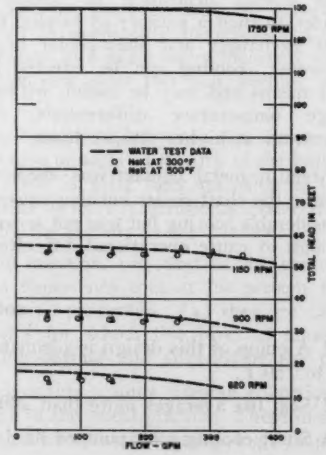

FIG. 6 COMPARISON OF WATER AND SODIUM-POTASSIUM DATA

tem were not readily obtainable when the sodium-potassium-system data were taken because of frozen or oxide-plugged pressure gages.

In general, the pumps have operated well for the purpose of which they were designed. No liquid-metal corrosion has taken place on any of the parts in contact with liquid metal. However, when liquid metal or vapor came in contact with the carbon-seal element, failure of the seal occurred shortly thereafter. Difficulty was experienced with one inlet-elbow casting where mold sand had penetrated the metal during casting. During subsequent liquid-metal operation, the sand reacted violently with the liquid metal to form a spongy layer of stainless steel on the surface of the casting.

The shaft-cooler bushing functioned satisfactorily as a primary liquid seal but was found unnecessary as a heat dam both because of the poor heat conductivity of the stainless-steel shaft and the effectiveness of the oil-cooling chamber. Shaft cooling by this method was found to be difficult because cooling the liquid metal from stream temperature to the desired shaft temperature caused deposition of dissolved oxides in such a manner as to plug the heat exchanger and shaft-cooler lines. However, cooling can be effected by this means and may be useful, without large temperature differentials, for operation at higher temperatures.

Metal-to-metal contact was encountered in the shaft-cooler bushing causing considerable scoring but was not serious enough to cause operational difficulties. Impeller thrust, dynamic vibrations, and thermal distortions were the causes of these metal contacts. No galling or shaft-balance difficulties resulted.

Additional heat was found necessary in the cavity below the seal adapter in the sodium pump because a frozen cake built up there and plugged the drain holes. A coiled calrod was added.

On several occasions it has been necessary to replace seals. The seal failures have been due to one or a combination of the following reasons:

1 Liquid-metal corrosion of the carbon.

2 Secondary silicone-rubber packing failures (as a result of oil contamination).

3 Foreign materials (dirt, grit, and so on).

4 High temperature causing:

(a) Differential expansion between the carbon and seal ring.

(b) Oxidation and decomposition of the oil in the seal (automotive motor oils operated most satisfactorily).

(c) Warping of the accurately machined surfaces resulting in a leak.

The experience gained in operating the pumps has presented the difficulties cited and enabled the seal life to be increased by adequate protection of the seal. The seal-maintenance problem has not been as difficult as originally anticipated. An average seal life of more than 2000 hr has been attained and is expected to improve considerably. Many thousands of hours of successful operation have been experienced over a period of 2½ years.

CONCLUSIONS

1 A pump of this design is adequate for pumping high-temperature liquid metals up to 750 F.

2 Seal life averages more than 2000 hr and is improving with experience.

3 Shaft cooling with pumped fluid is unnecessary at 750 F.

BOOK REVIEWS

HANDBOOK OF PROBABILITY AND STATISTICS WITH TABLES

By Burrington and May

Handbook Publishers, Inc.

Sandusky, Ohio

340 pages 5¼ x 7¾—50 Figures

Price $4.50

Reviewed by Mr. Joseph F. Fennell

The text in question lives up well to its promulgation as a handbook. As such it represents a fairly comprehensive condensation of the elements of statistics. The material is readable and well arranged. It does not, however, with the exception of chapter V, (15 pages), pertain noticeably to probability theory as the title would indicate. A notable feature is the quotation of a great many theorems without proofs. There should be no great objection here since this is in keeping with the authors' intention to present a manual.

It should be mentioned that Time Series, Statistical Inference and Sequential Analysis are topics in the text. This is of course unusual in a work of the kind in question. Although the treatment in these areas is brief their inclusion is very likely an excellent feature. It should constitute at least inspirational material for the majority of classes of readers proposed by the authors in the Preface.

This last brings us to the most important question, i.e., that of the potential usefulness of the text. It is the reviewer's experience that at the present time there are few people who have the two following properties: (a) they are called upon repeatedly to perform work in statistics for which this level of material constitutes preparation, (b) they lack training beyond that afforded by the text.

Finally it should be noted that the text contains a quite diverse collection of tables of the kind commonly regarded as useful in statistical practice. These include tables of the Poisson, X^2, Binomial and F distributions as well as log, log Γ, square, and square root lists.

ULTRA HIGH FREQUENCY PROPAGATION

By Henry R. Reed and Carl M. Russell

Published in 1953

John Wiley and Sons, Inc.

440 4th Ave., New York 16, New York

562 pages with Illustrations

Price $9.50

Reviewed by L. B. Wilson

In this text book the authors have amassed and presented in a single volume a wealth of up-to-date material in the field of tropospheric wave propagation, which heretofore has been available only in bits and pieces scattered through many texts, technical papers and engineering reports. A second and equally important feature of the book is the heavy emphasis on "The Systems Concept." This is defined as, consideration of the dynamic performance of the system as a whole. In presenting both the theoretical and practical aspects of propagation, the authors review the related system parameters, then relate theory and practice to these parameters and discuss the effect of variations of them in terms of overall system performance.

Considerable effort has been expended by the authors in attempting to provide a text book which would be of value to a wide range of professional interests. Specifically, the text treats each subject thoroughly, beginning with basic concepts and developing these step by step on through to include a rigorous mathematical analysis, hence the reader is privileged to proceed only so far as his interest or background dictates. The value of the book is further enhanced by the fact that the authors have included, for direct comparison to their theoretical treatments, the results of extensive propagation and systems performance measurements made over a period of several years. Correlation between theory and observed data seems to be good.

The rapidly expanding activity of electronics into the UHF portion of the radio frequency spectrum makes the advent of this book most timely. Additionally, the ever increasing demands on electronic systems and the electronic engineers who design them make a systems approach essential to the successful solution of modern engineering problems.

The closed loop or systems approach used by the authors in analyzing a mobile UHF communications system involves consideration of many factors not strictly in the field of radio wave propagation. These factors which include antennas, meteorology, modulation types, polarization, equipment circuitry, operator techniques and installation and maintenance practices are all discussed in detail.

This book will be of interest to all persons engaged in the technical phases of mobile communication, an excellent text book for both undergraduate and graduate students of electronics engineering and a valuable reference book for practicing electronics equipment and systems design engineers.

STRESS CONCENTRATION DESIGN FACTORS

By R. E. Peterson

Published in 1953

John Wiley & Sons, Inc. and Chapman & Hall, Ltd.

440 Fourth Avenue, New York 16, New York

X + 155 pages with Illustrations

Price $8.50

Reviewed by Lcdr. S. R. Heller, Jr., USN

As its author states in the Preface, "It is the purpose of this book to place in the designer's hands information which will enable him to improve his design calculations to the end that failure will be less prevalent and better balanced designs will be achieved." This purpose has been fulfilled remarkably well.

First, the format lends itself to frequent use because of its convenience. Helical binding has been incorporated to permit the book to open and remain flat with no tendency for pages to close. The use of an "edge finder" to index the design charts by shape and loading considerably simplifies the usual problem of finding the applicable case. Large full-grid charts permit easy entry, straight forward interpolation and accurate readings.

Secondly, the author prepares and protects the majority of his audience. He quite carefully explains his nomenclature. Then he probes the criterion of strength. Section B of Chapter 1 contains a remarkably lucid approach to strength theories: their derivations and applications. The remainder of the initial chapters is devoted to the determination of the design stress relations to be used in the drafting office. Throughout this development, the potential user is not side-tracked by ponderous mathematics from the primary theme. Instead, he is led directly to the desired stress relations, but, and this is important, copious references are provided should he desire to penetrate the background.

Lastly, the author has meticulously authenticated each chart to instill confidence in the users. Wherever possible, he has included the results of both experimental and theoretical work on the subject matter. Where this has not been possible, the author has used only the most reliable information.

It is unfortunate that the book is channeled primarily for the machine designer, because structural engineers are sadly in need of the same information. But this defect need not be long lived. Mr. Peterson has blazed an excellent trail by collection, calculation and codification of a vast amount of scattered data on the serious effects of stress concentrations.

BUSINESS FORECASTING

By Frank D. Newbury

Published in 1952

McGraw-Hill Book Company, Inc.

New York, Toronto, London

273 pages with Illustrations

Price $4.75

Reviewed by J. D. Crosby

This book deals with the principles and practice of business forecasting. The subject is presented primarily for the use of management in such a nontechnical approach as the subject itself will permit. The author brings to the book several years' experience in charge of forecasting at Westinghouse Electric Corporation plus the results of a study previously made of the forecasting work of 37 companies for the Controllers Institute.

The book opens with a discussion of forecasting as a tool for management. The importance and kinds of forecasting are defined. Forecasts are divided into two main categories: (1) external—relating to conditions external to the individual company, and (2) internal—including all forecasts that are limited to the operation of a single company.

The depression of the early 1930's and the conditions brought about by World War II led many business executives to look for better forecasting techniques. Two general methods for reaching agreement on forecasts have been designated as "agreement sought at lower organization levels and agreement sought at top organization levels." Mr. Newbury shows that top management may not have the complete picture when the lower organization level forecast committee presents a single report.

Fluctuations in business activity are explained as fluctuations in personal, business or government spending. The fundamental reasons why business activity fluctuates are developed. Since business activity is usually measured in dollars, the relationship between the supply of money, the volume of production, and the price level is outlined.

Investment expenditures which are usually financed from asset capital are considered by Mr. Newbury to be more significant for purposes of the business forecaster than consumption expenditures—income obtained from production.

He presents various methods for forecasting the Total National Production for the period following World War II. It is of interest to note that transfer payments (Government "handouts" of various kinds, without any offsetting service) have become an important source of personal income and purchasing power which must be considered by business forecasters.

Business forecasting by utilizing past experience, such as trends, past behavior, correlations and systematic evaluations are still considered to be the best guide. There are various incidents such as the unexpectedly high birth rate in the 1940's or the need for civilian durable goods after World War II which can adversely affect the projection of past experiences.

The use of business cycles for forecasting suffered an almost total eclipse in the early 1930's due to generally disastrous forecasting experiences of this period. However, the long residential building cycle, the intermediate cycle of heavy durable-goods industry, and the short textile cycle have been found to be most useful and significant in business forecasting.

While the Federal Reserve Index of Prediction covers only 30 percent of the national income, it does cover that part of business which fluctuates the most.

For the purpose of forecasting, the author contends that the price level is influenced by two different sets of factors: (1) monetary factors which include money supply and the volume of physical production; and (2) non-monetary factors of demand, also in relation to supply, and the cost of production.

Sales forecasting methods in the field of general business consist of two classes; methods which depend on the projection of past experience and methods which try to determine the current and future spending plans of customers or consumers.

This book is considered a pertinent text and reference for the engineer whose work perforce compels consideration of economics in terms forecasting events ahead.

DIED

The Society has received notice since the publication of the November, 1953, Journal that the following have died:

ARMSTRONG, W. E. F., Civil Member

BEEKMAN, ROYCE A., Civil Member

BROWN, HOWARD HAYES, Associate Member

EATON, REGINALD ORBIN, Naval Member

EGGLESTON, THOMAS J., Naval Member

JACKMAN, IRVING W., Civil Member

KING, J. H., Civil Member

LABBERTON, J. M., Naval Member

LAMBERTUS, PETER, Civil Member

McDONALD, ERNEST G., Naval Member

MASON, ALAN, Naval Member

PAUL, JAMES E., Associate Member

WATSON, WALTER W., Civil Member

CHANGES IN MEMBERSHIP

It is with much satisfaction and pleasure that it is announced that the following have joined the Society since the publication of the November, 1953, JOURNAL:

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Troller, Theodor H.
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Wilson, R. M.

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Brocklebank, Arthur P.
Elliott, Alex
Mackenzie, K. G.
Sample, Sam S.
Sneed, Harold E.

DROPPED FROM ROLLS

As required by the By-Laws, it became necessary on 31 December 1953, to drop from our rolls 103 members who were two years in arrears for dues.

ASSOCIATION NOTES

ORIGINAL ARTICLES

The editor of the JOURNAL is most anxious to obtain manuscripts of original articles on subjects of interest to naval engineers. Any manuscript accepted for publication becomes the property of the Society which copyrights it upon publication. Authors are paid from $40.00 to $150.00 depending upon length, interest and professional value.

The rules for manuscripts are as simple as we can make them.

1. They must be legible (typewritten, double-spaced preferred) since no proof is submitted to authors for correction prior to printing.

2. Single copy only is required.

3. Mathematical formulae used must be set up, preferably by hand printing, so that there can be no question as to symbols, subscripts and exponents.

4. Any drawing submitted must be black on white. A cloth or paper tracing is acceptable but not required.

5. Photographs may be negatives, but glossy prints are acceptable.

6. Include on a separate page a short biographical sketch(es) of the author(s). 50 to 100 words for each author is desired.

Manuscripts should be mailed addressed to:

Secretary-Treasurer
American Society of Naval Engineers
605 F St., N. W.
Washington 4, D. C.

Manuscripts accepted will not be returned unless specifically requested by the author. If returned, they will be in the condition which has resulted from the work of the printer and the engraver. Immediately following publication, the author is furnished 10 reprint copies of his article free of charge. Additional copies may be purchased from the Society if the request is received 30 days prior to the publication date which is the 25th of the issue month. Estimate of cost of additional reprints, which will vary with the nature of the article and the number of copies ordered, will be furnished on request as soon as possible after the article is set up.

Manuscripts not accepted will be returned, postpaid, by the Society.

Manuscripts which are accepted will be published in the earliest JOURNAL which has not yet been closed (60 days before publication) and for which sufficient material is not already on hand.

PHOTOGRAPHS

Photographs of current or historical interest to readers of the JOURNAL are desired. Any which are accepted by the Society will be purchased by the Society at a standard price of $5.00 each. Such purchase *will not* include any copyright by the Society, but the contributor must hold the Society free from any charge of violation of any previous copyright.

NOTICE OF DEATHS

The Society has no satisfactory machinery for obtaining notice of deaths of members. It is particularly desired that we receive such notice upon the death of any past officer, past member of the Council or member of more than twenty years' standing with photographs and short obituaries. It will be appreciated greatly if any member who learns of the death of a member will advise the Secretary-Treasurer.

SOCIETY LAPEL BUTTONS

Shown below is an illustration of the lapel button of the Society. It is believed that it will be conceded that this is a very fine dignified insignia. It is one-half inch in diameter.

The oak leaves and lettering are red on a gold background.

It is available to all members at fifty cents (50c) each.

Permission is granted to reprint any original article contained herein if the following conditions are met:

a) Credit is given to the JOURNAL with reference to the issue.

b) Credit is given to the author.

c) If the author is a military officer or a civilan employe of the Department of Defense, the following note shall be carried.:

> "The views expressed herein are the personal ones of the author and are not necessarily the official views of the Department of Defense or of a Military Department."

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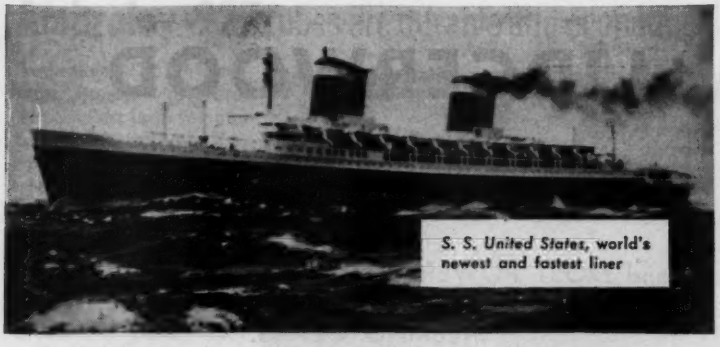

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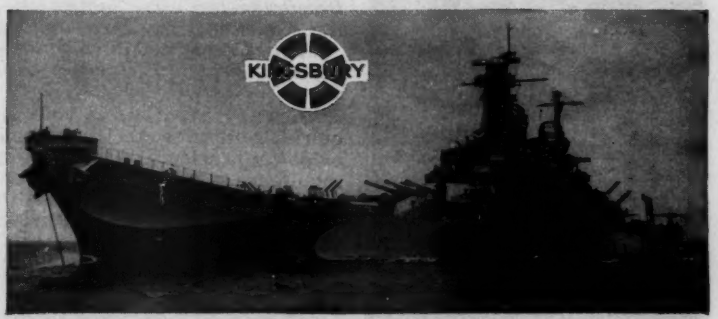

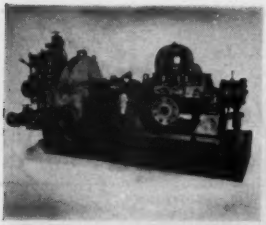
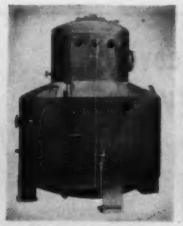
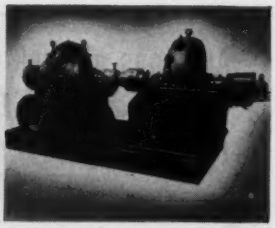

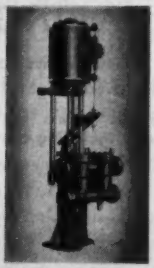
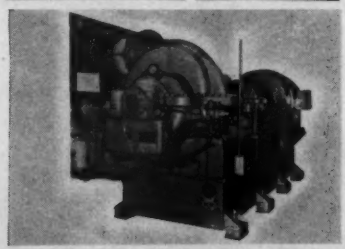
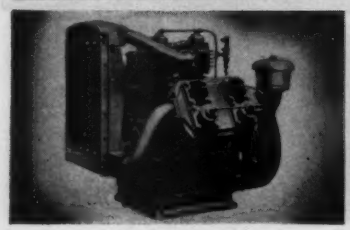

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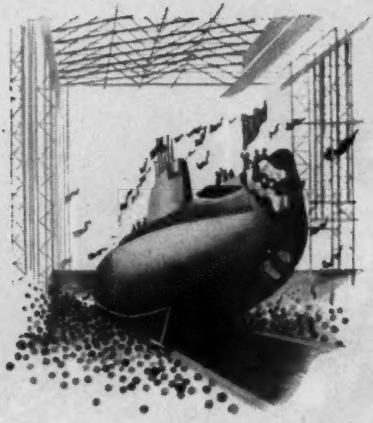

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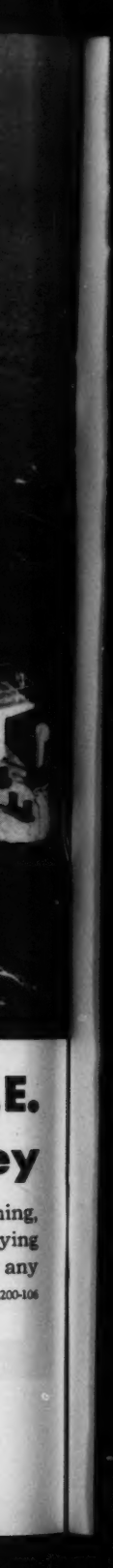

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